U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-259 442

Reactor Safety Study (WASH-1400): A Review of the Final Report

Office of Radiation Programs, Washington, D C

Jun 76

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA/520/3-76/009	2.	3. Recipient's Accession No. PB-259 442

4. Title and Subtitle

Reactor Safety Study (WASH -1400):
A Review of the Final Report

5. Report Date
Jun 76

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Office of Radiation Programs
Washington, D.C.

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

13. Type of Report & Period Covered

14.

15. Supplementary Notes

See also report dated 1975, WASH-1400(NUREG-75-014). (PC A07/MF A01)

16. Abstracts

In reviewing the Reactor Safety Study, the authors have tried to keep in perspective the original intent of the Study - to provide a technically sound overall assessment of accident risks from commercial nuclear power plants in the United States. They have also taken note of the limits to the scope of the Study and limitations which the report attaches to the applicability of the Study's results and methodology. With respect to the intent to provide a technically sound overall assessment of the accident risks, the authors have identified several significant areas in which they have found the WASH-1400 report either deficient or containing unjustified assumptions.

17. Key Words and Document Analysis. 17a. Descriptors

*Water cooled reactors,
*Nuclear reactor accidents,
*Environmental surveys,

Radiation hazards,
Risk,
Reliability.

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 18 H

18. Availability Statement National Technical Information Service Springfield, Virginia 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 137p
	20. Security Class (This Page) UNCLASSIFIED	22. Price 6.00/3.00

308008

EPA-520/3-76-009

PB 259 442

REACTOR SAFETY STUDY (WASH-1400): A REVIEW OF THE FINAL REPORT

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Radiation Programs

B1

EPA-520/3-76-009

REACTOR SAFETY STUDY (WASH-1400): A REVIEW OF THE FINAL REPORT

JUNE 1976

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
WASHINGTON, D.C. 20460

FOREWORD

The Environmental Protection Agency (EPA) considers the Reactor Safety Study (WASH-1400) to be a critical document relative to the potential environmental and public health impact of nuclear power. EPA's Office of Radiation Programs has committed significant resources to provide in-depth review of the draft and final version of that study. Our comments on the draft statement were made in two stages -- initial comments by our staff on November 27, 1974, and final comments on August 15, 1975. The final EPA comments included a detailed report from our contractor, Intermountain Technologies Inc. (ITI).

On October 30, 1975, the Nuclear Regulatory Commission (NRC) released the final version of WASH-1400 (NUREG-75/014). We have reviewed the final Reactor Safety Study Report to determine the extent that our comments on the draft report were resolved and to provide a technical evaluation of any new material or significant revisions to the draft report. The analysis of the consequences of reactor accidents, Appendix VI, had been completely revised and thus was material that had not been previously subject to review; it received particular attention.

We present in this report the results of our review of final WASH-1400, together with ITI's report of its review, so that they will be available as a resource to the scientific community and the general public. Because we consider the Reactor Safety Study to be of great value in the development of reactor safety and in the development of methodology for assessment of risk, the review comments published in this report are intended to provide constructive criticism which may be helpful to the NRC and others who may undertake further work in risk assessment.

We welcome comment on this report and would appreciate receiving any corrections or critical comments on the information and conclusions presented. Please send any such comments to the Environmental Protection Agency, Office of Radiation Programs (AW-459), Washington, D.C. 20460.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

CONTENTS

Page

SECTION 1. SUMMARY AND CONCLUSIONS 1-1

INTRODUCTION 1-1

GENERAL CONCLUSIONS 1-2

RESULTS OF EPA REVIEW 1-4

RECOMMENDATIONS 1-7

SECTION 2. HEALTH EFFECTS 2-1

A. Categorization of Upper, Central and Lower Bound 2-2

B. Dose Rate Effectiveness Factors 2-5

C. Mitigation of Effects by Medical Treatment 2-7

D. Radiation Bioeffects of the Thyroid Gland 2-7

E. Risk Estimates for Genetic Disorders 2-11

F. Radiation Dose Causing Specific Clinical Effect 2-13

G. Other Biological Consequences 2-13

H. Underestimates of Risk 2-13

I. References 2-16

SECTION 3. OVERALL REVIEW 3-1

A. Comments on the Consequence Calculation Description 3-1

B. Corrections or Information Additions Needed (Appendix VI) 3-5

C. Actions to Mitigate Radiation Exposures 3-9

D. Corrections or Information Additions Needed (other than in Appendix VI) 3-14

E. Review of Response to EPA Comments on Draft WASH-1400 3-21

F. References 3-22

SECTION 4. REPORT BY INTERMOUNTAIN TECHNOLOGIES INC. 4-0

SUMMARY AND CONCLUSIONS

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has always considered as part of its concerns the risk of accidents that may lead to contamination of the environment and subsequent injury to the health of the public. In our reviews of the environmental impact statements for light-water reactors (LWR's), which have been conducted since 1971, we have emphasized the need for a thorough evaluation of the environmental risk, including risks from accidents, associated with LWR technology. In August 1974, the U.S. Atomic Energy Commission (AEC) published for comment a draft report entitled "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400. This report presented the product of a major study, in total spanning three years and costing four million dollars, which was directed by Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The Reactor Safety Study is the first comprehensive study of reactor accident risks to utilize a systems analysis approach in order to quantify the accident risks in terms of probabilities and consequences, where historical and empirical data are inadequate. Because the Reactor Safety Study (the Study) may be considered the most definitive assessment to date of the risk from accidents, it is imperative that the Reactor Safety Study report be reviewed in depth and as impartially as possible so that the validity of the Study's methodology and results may be determined.

The Office of Radiation Programs of EPA initially conducted a comprehensive review of the draft report including the environmental consequence models, the general study methodologies and the conclusions, and issued formal comments to the Atomic Energy Commission on November 27, 1974. EPA obtained additional technical support for the review effort through a contract with Intermountain Technologies Inc. (ITI) of Idaho Falls, Idaho. The ITI effort was directed at examining the Study's evaluations of accidents and their event sequences to determine whether any significant failures of systems or equipment had been omitted or any major error or system biases of data analysis had been incorporated. For any area identified with possibly significant errors or omissions, the impact on the risks of the necessary adjustments in the variables or sequences of events was evaluated by ITI. The results of ITI's in-depth review and EPA's further comments were sent on August 15, 1975, to the U.S. Nuclear Regulatory Commission (NRC), which had assumed sponsorship of the Reactor Safety Study upon dissolution of the AEC. In October 1975, EPA published a report entitled "Reactor Safety Study (WASH-1400): A Review of the Draft Report," EPA-520/3-75-012, consisting of reprints of (1) EPA's comments of November 27, 1974,

(2) EPA's comments of August 15, 1975, and (3) the ITI report of its review.

On October 30, 1975, the NRC released the final version of WASH-1400 (NUREG-75/014). The principal changes in the final version from the draft are a complete revision of the consequence calculations in Appendix VI, the addition of an Addendum to the Main Report providing further explanation of the event-tree, fault-tree methodology, and the addition of Appendix XI providing responses to comments on the draft report.

As indicated in the Foreword to our report "Reactor Safety Study (WASH-1400): A Review of the Draft Report," we have undertaken a review of the final version of WASH-1400 using again the assistance of ITI. We have reviewed the final Reactor Safety Study report to determine the extent that our comments on the draft report were resolved and to provide a technical evaluation of any new material or significant revisions to the draft report. The analysis of the consequences of reactor accidents, Appendix VI of the Study, had been completely revised and thus was material that had not been previously subject to review; it received particular attention.

We consider the Reactor Safety Study a major step forward in understanding and estimating the risks from nuclear power plants. EPA supports the Study, its concept, and the need for continuing the effort to eventually arrive at a reasonable consensus of the level of risk associated with reactors. EPA's comments are primarily aimed at improving the quantitative risk estimates, and thereby increasing their value as an input to the risk assessment process.

EPA's review of the final Reactor Safety Study has been accomplished in two segments: the EPA staff has reviewed the new accident consequences section and the health effects models in Appendix VI of the Study, and the responses to previous comments; and ITI has reviewed the responses in the final report to their previous comments.

GENERAL CONCLUSIONS

In reviewing the Reactor Safety Study, we have tried to keep in perspective the original intent of the Study - to provide a technically sound overall assessment of accident risks from commercial nuclear power plants in the United States. We have also taken note of the limits to the scope of the Study and limitations which the report attaches to the applicability of the Study's results and methodology.

With respect to the intent to provide a technically sound overall assessment of the accident risks, we have identified several significant areas in which we have found the WASH-1400 report either deficient or containing unjustified assumptions. These are

(1) failure to address fully the health effects expected after an accident and to consider adequately a technical basis, which includes a broad range of perspectives, for estimating the incidence of the associated bioeffects, (2) the assumptions made in regard to evacuation as a remedial measure, (3) improperly or incompletely evaluated parameters used in determining accident event-sequences and probabilities, and (4) inadequate description of the analysis of the consequences of the release of radioactive materials to the environment.

It would be desirable in any review of a document such as the Reactor Safety Study to evaluate the sensitivity of the assessment to the various assumptions made in determining the estimates of population impact. Because the numbers of individuals exposed at the various doses of interest are not specified in the Study, EPA was not able to evaluate the assessment in terms of the range of uncertainties. We have found, however, that what we consider more reasonable assumptions in health effects, emergency actions, and estimates of probabilities of releases, would cause modifications to the overall risk analysis.

It appears that if late somatic health effects were adjusted in accordance with EPA's assessment of the numerical health risks, the estimates would increase by a factor of from 2 to 10. The potential change in the estimated early fatalities and injuries could not be determined by EPA from the information provided.

There are two deficiencies in the assumptions for evacuation as a protective action. The first involves the use of a constant 25 mile evacuation sector for all core melt accidents. This is at variance with present and planned practice and in some cases overestimates the risk and the need for evacuation, and in other cases underestimates the risk when larger groups may have to be evacuated.

The second set of deficient assumptions involves the amount of time that persons would be exposed prior to and during evacuation and the evacuation speeds. Because the details of handling of these parameters are lost in the description of the Study's modeling, it is difficult to assign quantitative values for the range of error in consequence estimates. The report itself, however, indicates that the early deaths and injuries would not be more than seven times as great if the evacuation were completely ineffective.

The effect of using other values of certain parameters in determining the outcome of specific accident sequences and their probabilities is also difficult to assess. An upper bound may be estimated for BWR reactor protection system failure using tightly coupled common mode failure; this dominant effect would apparently raise the overall risk (for the 100 reactors) by no more than a factor of 10. Bounding estimates on changes in other parameters, e.g., the

PWR containment failure pressure, indicate that individually they could not change the overall risk by more than about a factor of 3.

It is not possible to combine these uncertainties directly to obtain an overall corrective risk value because they address different aspects of probabilities and consequences and because the most likely values within these ranges cannot be derived from the limited information in the Reactor Safety Study report. However, we believe the Study has understated the risk based on underestimated health effects, evacuation doses, and probabilities of releases. The range is believed to be between a value of one and a value of several hundred.

The results of our review of the final report have not altered our opinion that the Reactor Safety Study provides a major advance in risk assessment of nuclear power reactors, and that the Study's general methodology provides a systematized basis for obtaining useful assessments of the accident risks where empirical or historical data are presently unavailable. In any effort to determine the acceptability of nuclear power in its present form, consideration should be given to the results of the Reactor Safety Study only as suitably modified to correct for the underestimation of health effects and other deficiencies noted. Such a determination should consider that the risk of severe accidents, such as described in the Reactor Safety Study, is only a portion of the overall risk and that the rest of the fuel cycle, sabotage, and lesser accidents are also among the contributors to the risk. We emphasize that the risk comparisons made in the Reactor Safety Study are only one step toward a determination of risk acceptability of nuclear power.

RESULTS OF EPA REVIEW

1. The most significant disagreement is that associated with the health effects model in Appendix VI. We particularly disagree with the WASH-1400 conversion of radiation exposures to health effects, which tends toward underestimation of the health effects. Such risk estimates are highly uncertain on the basis of present knowledge. We consider the adequacy with which these uncertainties are addressed central to providing an informative estimate of reactor safety. In the environmental impact statements developed by the Nuclear Regulatory Commission (NRC), estimates of radiation risk have been based on the recommendations prepared for the Federal Radiation Council (whose function now resides in EPA) by the National Academy of Sciences' BEIR Committee. The BEIR Committee's recommendations were prepared in response to a request of Congress that the National Academy of Sciences recommend numerical risk estimates for Federal use. These

recommendations were not followed by the NRC in the development of the Reactor Safety Study. Instead, an ad hoc advisory group was specifically established to provide risk estimates for the final report, the BEIR report having been used in preparation of the draft. While this ad hoc group developed many innovative and original views on assessing radiation risk, it is this Agency's finding that based upon current interpretation of accepted data many of the risk assumptions made in the Reactor Safety Study are premature and that the advice of the National Academy of Sciences was not used judiciously.

2. In examining the discussion in WASH-1400 of actions to mitigate radiation exposures, we find that although we do not agree with the selection of a few parameters and concepts, the general approach appears to be suitable, developed as it was in advance of EPA's issuance of relevant guidance. It appears, however, that incomplete consideration had been given to requirements that may indicate the use of evacuation as a protective action. Pending the issuance of EPA guidance dealing with protection from exposure to contaminated media, the reliance by the Reactor Safety Study on recommendations of the Federal Radiation Council and the Medical Research Council of Great Britain regarding long-term exposure dose criteria for external radiation and ingestion via milk and other pathways also appears to be reasonable. We concur with the statement in WASH-1400 that there is need for further work in this area.

3. The report does not present sufficient information illustrating the variations in consequences and risk to nearby population groups caused by differences in site-specific circumstances, which may be masked by the restriction of the analyses of the six composite sites.

4. EPA commented on a number of areas that appeared to be deficient in the draft report. The final WASH-1400 provides satisfactory responses to a number of those comments, but not to all. Of those previously-noted deficiencies which remain in the final report, the ones for which an evaluation was made are judged to have no significant effect individually in the major conclusions of the Study. By significant, we mean the possibility of changing the overall estimate of risk in WASH-1400 by as much as a factor of ten. However, the deficiencies do tend to reflect on the care with which the draft and final reports were prepared and therefore they are worthy of mention.

5. A significant deficiency found in the consequence calculations was that the presentation lacks a description of the specific analytical framework applied, i.e., a description of the way the parts of the consequence calculations are put together. The final WASH-1400 needs a clear, concise description of the calculational process, which clearly distinguishes it from all the supporting arguments, rationale, and background material. In addition, intermediate values from the calculational steps for specific cases should be provided. We find that insufficient information has been provided for others who may wish to utilize the developed techniques or even to trace through them. This information would facilitate an improved and fair assessment of the results and their uncertainties and would allow the scientific community to utilize and improve on the developed techniques.

6. The final WASH-1400 provided additional information and clarifications in response to comments by our contractor on the draft report. This resulted in many significant improvements in the report. ITI drew the following conclusions from their review of the final WASH-1400; we have examined them and their bases and we concur in these conclusions:

(a) The final version of WASH-1400 has been improved compared to the draft version. The conclusions from ITI's review of the draft version are, however, judged to be applicable, with minor modifications, to the final version.

(b) The majority of the errors, omissions, inconsistencies and debatable assumptions in the final WASH-1400 do not have a significant impact on the overall risk assessments. (ITI did not address the health effects models.)

(c) The summary presentations in the final WASH-1400 comparing nuclear power risks with other man-made risks are sometimes misleading and incomplete. This tends to undermine the strength of the report's conclusions. Deficiencies in the presentation include the failure to illustrate calculational uncertainties in reactor accident risks, the comparison of calculated reactor accident risks with other types of risks based on actuarial data without stressing the differences, and the obscuring of latent deaths in reactor accident risks.

(d) The risk assessment for the boiling water reactor transient without scram appears to be the most significant analysis problem found in the final (and draft) WASH-1400, which may underestimate the risks.

(e) The final WASH-1400 appears to have improperly or incompletely evaluated human reliability, PWR small break analyses, common mode failures and some aspects of design adequacy. Further, there is insufficient information in the report to quantify the impacts of these deficiencies on risk evaluations.

(f) The validity of using the Surry reactor as a basis for calculating the risks representative of all PWR's requires additional justification, since only about 20 percent of all PWR's scheduled for operation in 1980 are similar to the Surry design.

(g) The assessment of the functionability of the Emergency Core Cooling System (ECCS) appears incomplete and some of the stated conclusions may be misleading.

(h) The assumed pressure which leads to failure of the PWR containment appears high and the basis provided for its selection was found to be deficient.

(i) Of the 45 deficiencies identified in ITI's comments on the draft WASH-1400, 34 remain in the final report, with 29 having the potential of altering the calculated risks. Sixteen of these 29 are judged to have an insignificant impact on the results. One deficient area (BWR transient without scram) may have a significant impact. The potential of the remaining 12 for altering the risks was undetermined.

RECOMMENDATIONS

1. As a supplement to the Reactor Safety Study report, further estimates should be made of the health effects from accidents using different upper bound, central and lower bound risk models.

The Agency suggests that (a) lower bound estimates should be based on absolute risk, 30 year plateau, and dose rate effectiveness factors not smaller than 0.5; (b) central estimates should utilize an average of the absolute and relative risk estimates stated in the BEIR report by the National Academy of Sciences; (c) while upper bound estimates may require more speculation about additive and synergistic health hazards than is warranted at this time, some consideration of the sensitivity of the estimates to the use of a convex relationship appears justified, or, alternatively, the relative risk estimates in the BEIR report with a life risk plateau could be used as a surrogate.

2. The Reactor Safety Study efforts should be continued in order (a) to provide verification of their applicability to a broad spectrum of light-water reactors, including those beyond the first 100 (considered in WASH-1400); (b) update the risk analyses as more operational information and improved analytical techniques are developed; and (c) to expand the applicability of the WASH-1400 techniques to the process of licensing nuclear reactors.

3. As incidents occur in the nuclear power industry, their significance relative to reactor safety should be evaluated and placed into meaningful perspective.

4. As recommended in the Study, the methodology of WASH-1400 should be extended to evaluation of Floating Nuclear Power Plants, LMFBR's, LWBR's and HTGR's as design and operational data become available in sufficient detail to make the effort worthwhile.

5. Further efforts in this area should assess the variations introduced by site-specific circumstances so as to provide additional insight into the variability of the consequences and the risk to nearby population groups.

6. A supplemental report or addendum to WASH-1400 should be prepared to detail the analytical techniques, including intermediate steps, some examples, and the computer programs used to calculate the consequences given in Appendix VI.

SECTION 2. HEALTH EFFECTS

The number of expected health effects is the bottom line in any assessment of reactor safety. Such risk estimates are highly uncertain on the basis of present knowledge and the adequacy with which these uncertainties are addressed is central to providing an informative estimate of reactor safety. In the environmental impact statements developed by the Nuclear Regulatory Commission (NRC), estimates of radiation risk have been based on the recommendations prepared for the Federal Radiation Council (whose function now resides in EPA) by the National Academy of Sciences' (NAS) BEIR Committee. The BEIR Committee prepared the recommendations at the behest of Congress that the NAS recommend numerical risk estimates for Federal use. These recommendations were not followed by the NRC in the development of the Reactor Safety Study. Instead, an ad hoc advisory group was specifically established to provide risk estimates for the final report, the BEIR report having been used in preparation of the draft WASH-1400. While this ad hoc group developed many innovative and original views on assessing radiation risk, it is this Agency's finding that many of the risk assumptions made in the Reactor Safety Study are not generally accepted as yet within the scientific community, and that the advice of the NAS was not used judiciously.*

An objective of the Reactor Safety Study (the Study) was to make a realistic assessment of the health risks associated with potential reactor accidents and to indicate the uncertainties in such assessments. In some cases, the Study failed to address fully the health effects expected after an accident and to consider adequately a technical basis for estimating the incidence of the associated bioeffects, which includes a broad range of perspectives. Therefore, the Study did not provide an accurate and complete understanding of the health risks associated with a reactor accident. At the least, the Study should have provided a better analysis of the following problems:

- proper categorization of upper, central and lower bound somatic health risk estimates,

- justification of the selected dose rate effectiveness factors (DREF) for chronic and acute bioeffects,

---

*EPA has recognized the continuing need for the National Academy of Sciences to update their review of radiation health effects. EPA-contracted reports on Plutonium Hot Particle Health Effects and Benefits of Radiation are to be completed momentarily by NAS. A contract for an NAS review of information of health effects since 1972, including dose-rate effects, has already been initiated by EPA.

- minimal, supportive and heroic treatment for the mitigation of acute effects as hypothesized in the report,

- radiation bioeffects of the thyroid gland,

- risk estimates for genetic disorders,

- estimates of radiation doses that result in specific clinical health effects.

These defects in the report are discussed more specifically below.

A. Categorization of Upper, Central and Lower Bound Risk Estimates

The Reactor Safety Study categorized the long term health risk from cancers into three categories: (1) an upper bound estimate for which the linear, non-threshold dose-effect model was assumed; (2) a central bound estimate where the expected cancer deaths, based on the linear non-threshold model, are reduced via a set of DREF, supposedly in order to account for differences in health hazards following exposure to low LET radiation at low doses and low dose rates; (3) a lower bound estimate where a threshold dose for radiocarcinogenesis is assumed.

While EPA does not find consideration of upper and lower bound risk estimates inappropriate for a study of this type, we believe a more balanced consideration of the models used to describe each risk category is appropriate. Contrary to the assumption in the report, the non-threshold linear model does not lead to the most conservative estimate of radiation risks.

A more accurate categorization of upper, central and lower bound risk estimates would be to define them in terms that truly reflect the several types of dose-response concepts that have been considered by the scientific community, namely: convex upwards response[1-5], linear response[6-11], and concave upwards responses[12-22]. Since the Reactor Safety Study did not use the proper definition for each category, its estimates of health risks are biased.

1. To establish an upper bound estimate of health effects, it would have been more realistic to predict cancer incidence on the basis of a convex upwards dose response rather than a linear response. Several investigators, including Baum[1,2], Brown[3], Gibson, et al.[23], Mole[20], Morgan[5], Casarett[24] and Lappenbusch[25] have suggested that given certain defined conditions, a convex dose response may occur. Baum[1,2] reviewed and analyzed the radiation dose-tumor (cancer) incidence in mice, rats and man and showed that carcinogenesis can be represented by a simple power function of dose via the form $E = CD^n$ where E = effect, C =

constant, D = radiation dose and n = constant. Baum indicated that the exponent (n) is frequently less than 1.0 (0.19 for lung cancer, 0.35 for stomach cancer and 0.5 for female breast cancer) signifying that the dose-effect curve is convex upwards, particularly at low doses. Baum's explanation is based on the arguments that (1) humanity is a heterogenous population with mixed predisposition to cancer due to genetic differences and differential sensitivity to multiple stressors and (2) at low doses in a heterogenous population, a fraction of the people respond to one-target kinetics and, thus, cause a steeper slope in the dose response curve at low doses as opposed to a reduced slope at the higher doses where the less sensitive fraction of the population requires additional injury to show effects.

As stated in the Office of Radiation Programs' "Policy Statement on Relationship Between Radiation Dose and Effect," March 10, 1975, EPA believes that the linear non-threshold model as developed in the BEIR Report[26] provides the best estimates of human health risk. However, this model may not be conservative at low doses. EPA recognizes[27] that much of the available data for the risk coefficients given in the NAS-BEIR Report are based on high doses where cell killing may have perturbed the carcinogenic dose response. This has been discussed by Baum[2], Mole[4] and Morgan[5]. A convex dose response relationship for carcinogenesis should have been considered in the Reactor Safety Study, since it appears to be as scientifically tenable as the threshold hypothesis used in the Study for lower bound estimates.

2. The National Academy of Sciences BEIR Committee recommended the use of the linear non-threshold model for radiocarcinogenesis to the Federal Radiation Council as a best estimate of radiation risk, and in view of recent data[6-11] indicating its applicability at low doses, it is surprising that it was not used as the central estimate in the Reactor Safety Study. No explanation is given in the Study for electing not to use the BEIR Committee relative risk estimates. Such a central estimate of risk should have weighted equally absolute and relative risk estimates or, as the BEIR Committee did, list these two methods as upper and lower bounds on the "central estimate."

The Reactor Safety Study neglected recent information in support of the linear non-threshold hypothesis:

(a) Modan, et al.[6] recently completed a retrospective study of 10,902 children who received a thyroid dose of approximately 6.5 rads during x-ray treatment for tinea capitis. Approximately 17.5 years thereafter, Modan found that the irradiated group had significantly higher absolute risk estimates for malignant and benign head and neck tumors, especially of the brain, parotid and thyroid gland, than did the controls. Calculating the absolute risk estimate for thyroid tumors in Modan's observation (8.1 excess cases/10^6/yr/rad) and comparing with the BEIR Report (2-9 excess cases/10^6/yr/rem), a linear, non-threshold relationship seems most appropriate for the low LET radiation applied. It should be noted that rather than considering these new data to indicate linearity at low doses, the authors of the Reactor Safety Study preferred to set thyroid cancer in a special category of its own. Apparently, to do otherwise would have negated use of a threshold carcinogenesis dose in the "lower bound" estimate (see below).

(b) Stewart and Kneale[9] conducted an epidemiological study on children dying from cancer within ten years after birth who had experienced in-utero exposure to x-rays during obstetric investigations. Recent studies by Halford[23] and Newcombe and McGregor [29] indicates that for these in-utero exposures the leukemia rate was linear with doses as low as 0.25 - 0.5 rad. Mole [30] has shown that Stewart's results were not biased by a predisposition to leukemia in the population studied.

(c) Animal studies also indicate linearity for carcinogenesis at low doses. Shellabarger et al.[8] subjected 40 day-old female Sprague-Dawley rats to ^{60}Co gamma rays at 40 R/min where exposures ranged from 15.6 - 250 R and found, as in prior studies, an apparent linear relationship, for both acute and fractionated schemes for the incidence of mammary cancer. Borek and Hall[10-11], working with golden hamster embryo cells, found that neoplastic cell transformation shows a convex dose response relationship below 1-10 rads, a linear response above 10 rads and a response reflecting reproductive cell death after 300 rads or more.

3. The Reactor Safety Study should have included in the lower bound category all of the concave dose-effect models, namely: sigmoidal, quasi-threshold, quadratic and dose-squared. Such response concave models could have taken into account the proposed DREF suggested in the Study and possibly a threshold dose if repair processes can possibly justify its existence. Caution should have been taken, however, not to confuse and translate well known radiation injury studies where cellular, organ depletion and survival studies demonstrate clearly that biological repair occurs, to the case of radiation carcinogenesis, because of the lack of knowledge of whether the same mechanisms apply.

B. Dose Rate Effectiveness Factors

The Reactor Safety Study does not provide an adequate scientific basis for the DREF used, i.e., 0.2 for somatic bioeffects (cancers) and 0.5 for acute injury (radiation injury to bone marrow). While the Reactor Safety Study uses the DREF to obtain a five-fold reduction in the estimated number of cancers due to an accident, it would appear that several factors indicate this choice is not prudent. These factors are examined below.

1. The Reactor Safety Study leaned heavily on a study by Mays, Lloyd and Marshall [17] to obtain the numerical values used. An examination of the references given by Mays, Lloyd and Marshall[17] shows that the DREF values could range from approximately 0.1 to greater than 1.0. Furthermore, fractionation studies, such as those considered by Mays et al.[17] have been shown to be greatly influenced by radiation conditioning[31], and that reducing the dose rate results in wide variations in recovery capabilities among animals[32]. Finally, Mays et al.[17] failed to differentiate between results obtained from chronic irradiation at low dose rates (the case of interest here) and studies where a fractionated dose was delivered at high dose rates intermittently over a relatively long test period. For example, Mays et al.[17] characterize dose rates delivered at 8.5 R/min by Anderson and Rosenblatt[33] as 0.006 to 0.06 R/min depending on the period of time over which the several fractional exposures were given. In the discussion below, this will be referred to as the average fractionated dose rate (AFDR) rather than dose rate.

2. Mays et al.[17] indicate a chronic DREF of 0.08 for life shortening in beagles based on an experiment by Anderson and Rosenblatt[33]. However, in reviewing the data by Anderson and Rosenblatt, it is evident that the data indicate that in these experiments life shortening is influenced only by total dose and not dose rate, as shown in Figure 1. The data reproduced in Figure 1 indicates that 300 R is more effective than 100 R for a given dose rate and that mortality following 100 R is greater than that in controls for animals surviving longer than nine years post-exposure. However, the mortality patterns are not dose rate dependent, but rather show a DREF of 1.0 since there was no significant difference in percentage cumulative survival of dogs at any time in the period 0-14 years post-exposure, whether they experienced an average fractionated dose rate of 0.06 R/min or 8.5 R/min. Using Mays' method of analysis, it is possible to use these same data to show a DREF greater than 1.0; for example, a DREF of 3.0 could be obtained by comparing animals exposed to 300 R at 8.5 R/min to those given 100 R at an AFDR of 0.0008 R/min. Obviously, this is not a valid number, but rather shows the need for care in interpreting such data.

3. It should be pointed out that in all of the studies cited by Mays et al.[17], where a relatively long life span animal was involved, the results of their analysis are rather unconvincing. For example, a calculated DREF of 0.08 was obtained by Mays et al.[n] using data reported by Casarett and Eddy[34]. These animals (dogs) were exposed at 0.06, 0.12 or 0.60 R/day. Yet, the average age at death for each test group was essentially unchanged (12-13) years, indicating a DREF of 1.0. However, using Mays' formula, DREF values ranging from 4.4 to 8.9 could be calculated.

4. The rodent data cited by Mays et al.[17] is somewhat more convincing. Using data by Shellabarger and Brown[35], Mays et al. calculated a DREF of 0.68. However, upon plotting percentage mammary cancer in rats following exposures at 0.03 R and 10 R/min versus total radiation dose, it becomes obvious that in this study DREF values range from 0.23-1.0, depending upon which dose levels are compared.

Mays et al.[17] also referenced papers by Mole[20]; Grahn, Fry and Lea[21]; Upton, Randolph and Conklin[36]; and Doniach[37]. These papers provide chronic DREF values of approximately 0.14; 0.19; 0.07; 0.45; 0.14; 0.26; and 0.1 respectively. While these DREF values do support Mays et al.[17] and their suggestion that animal experiments indicate that in some cases radiocarcinogenesis is less at low dose rates, the applicability of these data to humans is very tenuous. The paper by Mole[20] is a case in point. He shows that the length of time over which the fractionated doses are delivered is an important factor in determining the resultant carcinogenicity and that long exposure periods can lead to higher cancer incidence. Obviously, only limited conclusions that are applicable to radiocarcinogenesis can be gained from studies on inbred mouse strains. EPA is aware that research in this area is very active at present and that ongoing studies may result in a much better foundation for the use of DREF risk evaluations. However, their use in the Reactor Safety Study would appear to be, at the least, premature.

5. The applicability of a dose rate effectiveness factor to acute effects due to radiation is better established than for cancer where such studies are just beginning. However, the application of the 0.5 DREF for acute injury is not well documented in the Reactor Safety Study. Clinical evidence showing less acute effects for protracted (fractionated) exposures is conflicting[31]. When fractionated exposure patterns are used, the first dose in the fractionation may well condition the response to the succeeding dose fractions. For example, Ainsworth et al.[32] have shown that the $LD_{50/60}$ for sheep at 4 R/min varied from 144 to 540 rads depending on the length of time following an earlier conditioning dose.

C. Mitigation of Effects by Medical Treatment

Death following acute exposure may be underestimated in the Reactor Safety Study due to incorrect assumptions concerning availability of specialized medical treatment for acute radiation injury. In the report, lethal doses to the population near an accident are estimated as 340, 510 or 1,050 rads depending upon whether or not minimal, supportive or heroic medical treatment is provided. It appears that in the case of a severe accident some 5,000 people would receive a dose of 350-550 rads and, thus, need heroic as opposed to minimal or supportive treatment. Since there are perhaps only 12 hospitals in the U.S. which could provide heroic treatment to, at most, 50-150 people, this leaves about 4,900 people without such treatment. The heroic treatment scenario would appear to be impractical. Its use implies that reactor safety assurance is dependent upon the surrounding population's acceptance of such treatment and the availability of medical care to a degree that is unrealistic.

D. Radiation Bioeffects of the Thyroid Gland

Thyroid injury is an important aspect of a reactor accident. The associated risks may have been underestimated in the Reactor Safety Study. The stated thresholds for radiation thyroiditis (25,000 rem) and hypothyroidism post-exposure (20 rem) may be high by factors of 2.5 and 2, respectively.

1. In Section H2 of Appendix VI of the Study, concerned with acute effects of ionizing radiation on the thyroid, it was reported that Beierwaltes and Wagner[38] had found in 1956 that radiation thyroiditis seemed to occur 3-7 days post-ingestion of radioiodine in 4-5 percent of thyrotoxicosis patients. Unfortunately, the Study failed to mention that Beierwaltes and Wagner revised their position twelve years later (1968) suggesting that thyroiditis would develop within 1-2 days post-radioiodine treatment in approximately 5 percent of the patients. They noted also that symptoms of thyroiditis seldom lasted over 24 hours but might persist as long as 3-7 days. Beierwaltes and Wagner[38] also noted that radiation thyroiditis could lead to hemorrhage into the thyroid gland in patients on anticoagulant drugs.

2. Although presence or absence of clinical thyroiditis was not reported, Miller et al.[39] reported 6 to 8 patients receiving over 7 mCi of iodine-131 (estimated dose - about 10,000 rads) showed histologic changes in the thyroid compatible with acute thyroiditis or Hashimoto's thyroiditis depending on how long after exposure they were examined. An additional 4 of 12 patients who received between 0.9 and 5.5 mCi of iodine-131 (estimated dose

1,200 to 7,200 rads) may have shown some histologic evidence of thyroiditis. Therefore, it would appear that the subjective evaluation of the patient on the extent of thyroiditis is not a good guide to actual incidence and that the threshold value of 25,000 rem suggested in the report may not be appropriate.

3. In the discussion of thyrotoxicosis (thyroid storm) in Section H2 of Appendix VI, reference is made to a U.S Department of Health, Education and Welfare (HEW) publication (HRA-74-1767) suggesting that 29 cases of thyrotoxicosis occur per 100,000 persons (the HEW publication should be credited as HRA-75-1767). The effects of this condition are likely to be more important than indicated in Appendix VI. The assessment by Ingbar and Woeber[40] used in the Reactor Safety Study that death may occur in 20 percent of thyroid storms should have been modified to reflect that this 20 percent mortality occurs under an intensive hospital regimen to combat the thyroid storm. (What might happen in an untreated group was not estimated.) Unless hospital care is available, mortality may run higher in cases of thyroid storm than the report indicates.

4. The threshold for hypothyroidism at low doses is not well established. The findings of Hamilton and Tompkins[41] were discussed but results for two patients were excluded, even though hypothyroidism occurred in one case after a dose of about 10 rem, because of a prior goiter condition. However, goiterous persons will be exposed in accident situations and all of the data should have been included in the risk estimates. The relatively high incidence of goiter in the U.S., particularly north of the 40th parallel, suggests that 1 percent to 5 percent of the population is so affected and may be at risk for the low dose effects indicated in the study by Hamilton and Tomkins[41]. The 20 rem threshold for hypothyroidism is not well based. If there is a threshold, a better estimate would be about 10 rem.

5. The discussion (Section H3.4.2 of Appendix VI) of hypothyroidism after high dose (>2,500 rem) exposure to iodine-131 encompasses a rather interesting assumption, i.e., since surgical treatment yields hypothyroidism at an incidence of about 0.7 percent per year, this same percentage should be accepted as the spontaneous rate of conversion of Grave's disease to a hypothyroid condition. This assumption is not fully justified, for the following reasons:

(a) The relative incidence of hypothyroidism depends partially on the amount of thyroid tissue remaining. In some surgical series a portion of the gland is purposely left to prevent hypothyroidism;

(b) delayed partial or complete loss of thyroid function may result from either progressive restriction of blood supply or autoimmune destruction of the thyroid remnant;

(c) defective organic binding of thyroidal iodine follows radioiodine therapy so that the chances of hypothyroidism are increased. (See Beierwaltes and Wagner[38] and Ingbar and Woeber[40] for a more detailed discussion of why surgery and radioiodine therapy may lead to hypothyroidism.)

The phenomena involved in postablation development of hypothyroidism are quite unique to this treatment modality. The associated changes in LATS and TSH response may also be applicable only to stresses due to radioactivity. These factors were not considered in the report.

6. Section H4.6.2 of Appendix VI of the Reactor Safety Study is concerned with the effects of iodine-131 ingestion on children. It draws quite heavily from Marshallese exposure data to imply that the reported nodularity rate observed there was influenced by a high degree of scrutiny and suspicion, leading to detection of smaller nodules than in general clinical practice so that the estimates used in the Study may be unduly conservative. However, several factors indicate that the opposite is more likely to be the case. What is not mentioned in the discussion of Marshallese experience is that:

(a) In 1965, the more heavily exposed, Rongelap group was placed on exogenous thyroxine to nullify the stimulating effects of TSH on the thyroid gland and inhibit development of benign or malignant nodules;

(b) In 1971, the Ailingnae group was placed on exogenous thyroid hormone; and

(c) In 1974, all other exposed Marshallese, about 3/4 of the total group, were included in the hormone therapy program to prevent the occurrence of more cancers[42]. As a result, followup of the untreated patients group is limited. The results of the followup at 20 years may have been confounded by the medical treatment initiated after the first 10 years and are compromised as far as statistical risk estimates are concerned.

A possible implication, or inference, derivable from the data considered in the Study is that: if persons are exposed to radioiodine and their thyroid is not removed surgically, then they should be placed on exogenous thyroxine immediately to reduce their chance of developing thyroid cancer. This is the handling of the problem that was developed in the Marshall Islands. The applicability of this solution to a U.S. accident situation was not developed in The Reactor Safety Study, nor were consequences of surgical and hormonal intervention.

7. In summary, there are four basic areas of disagreement concerning the risk to the thyroid due to radiation. First, in the area of acute effects - radiation thyroiditis, there is evidence that the threshold for thyroiditis may be 10,000 rads or lower. Perhaps it would be a subclinical thyroiditis but it would be present. A recommendation of 10,000 rads as the radiation thyroiditis threshold seems more appropriate than the 20,000 rad limit utilized in the Reactor Safety Study.

Second, in the area of continuing effects - hypothyroidism, the data presented in Appendix VI indicates at least one case occurred at 10 rem or less. In Table VI H-3 effects are shown in the 30 to 80 rem exposure range but not in the 10 to 30 rem exposure range. However, in view of the short followup (14 years) and the small numbers involved (146 persons), it may be premature to say that the threshold for hypothyroidism is 20 rem. A recommendation of 10 rem for the radiation hypothyroidism threshold seems more appropriate.

Third, in the area of risk estimation, it is important to indicate that although a risk estimate of 4.6 cases/10^6/rem/year is suggested, the curves shown in Figure VI H-1 do not show much linearity nor does data in Doniach[43] nor Jackson[44]. The data in Figure VI H-1 and Table VI H-3 can also, perhaps more grossly but accurately, be fit by the following equation:

Risk = $[40 \times 10^{-6} + 12(n-1) \times 10^{-6}\ \text{yr}]$ cases of hypothyroidism per rem for n years after exposure.

8. Finally, relative to thyroid cancer, an upper bound estimate of risk compared to external x-rays of 1/10, a central estimate of 1/20 and lower bound estimate of 1/60 is not adequately justified. This is especially so if the latent period for cancers due to iodine-131 is similar to that for external radiation (up to 40 years) as indicated in Appendix VI to the Reactor Safety Study.

At the present time the estimate made by Dolphin and Beach[45] of iodine-131 being about 1/10 as effective as x-rays in inducing thyroid neoplasia, is a reasonable estimate. This same general estimate is supported by Cole[46].

E. Risk Estimates for Genetic Disorders

Estimates of genetic risks due to radiation accidents are not as clear cut as indicated in the Reactor Safety Study.

1. In Section I4 of Appendix VI, concerned with the differential sensitivity of males and females, the presentation suggests that only slight numerical adjustments need be made to BEIR Report estimates of genetic effects. However, the actual situation is the subject of active scientific debate and the question of differential sensitivity of spermatogonia and oogonia is being investigated by numerous researchers. UNSCEAR[47] suggested the mutation rate in males was about 1/3 as great at low dose rates as at high. Also, UNSCEAR[47] reported that, regardless of dose rate effects, there is a threshold dose rate below which the cellular repair system is unaffected. This threshold is higher in spermatogonia than in oogonia.

   Abrahamson[48] has indicated that the mouse oocyte is so radiosensitive that at the dose rates used in studies of mouse oogonia, the reduced genetic effects observed are due to cell death rather than to cellular repair mechanisms. Therefore, the BEIR Report estimate of 0.25×10^{-7} per locus per rem may be a factor of 2 in error. Since the male rate of 0.5×10^{-7} mutations per locus per rem was divided by 2 to get the average rate for males and females, if the estimate is in error, it is low rather than high.

2. Crow[49] has suggested that the appropriate single-locus mutation rate is 2.6×10^{-7} per locus per rad for high dose rate radiation and perhaps 1/3 to 1/4 as high for chronic radiation. This would be $0.6 - 0.8 \times 10^{-7}$ mutations per locus per rad, compared to the original BEIR Report estimate of 0.25×10^{-7} mutations per locus per rem. If Abrahamson and Crow are correct, the BEIR Report estimate may be a factor of 140 percent to 220 percent low. Indeed, Lyon et al.[50] have suggested that the mutation rate increases with decreasing dose rate (below 0.001 R/min) so that the 1972 BEIR estimate would be an order of magnitude low. However, we believe it unlikely that the 1972 BEIR estimate is as low as Lyon's suggestion.

3. In Section I5.1.1 regarding single-gene disorders, a discussion of autosomal recessive mutants is made where the frequency is given as q and the post irradiation frequency as $q + \Delta q$. This implies that there is no loss of the recessive genes between generations. A more accurate description of the post irradiation frequency would be

$$q(1 - s) + u(1 - q)/(1 - sq)$$

where: s is the probability that the gene will be eliminated in any one generation; u is the mutation rate for the dominant gene, Q, to recessive gene, q, at that locus (perhaps the sum of radiation induced and "spontaneous" mutation rates)[53].

Therefore, to show that there is little change in the incidence of a condition instead of showing that recessive $q^2 = (q + \Delta q)^2$, it must be shown that:

$$q^2 = [q(1 - s) + u(1 - q)/(1 - sq)]^2$$

In all of the discussions in both the BEIR Report and Appendix I of Appendix VI of the Reactor Safety Study, the questions of (1) incomplete penetrance, (2) variable expression, (3) multiple alleles and related questions have been avoided or neglected[52]. These factors will, of course, affect the final risk estimates.

4. In Section I5.1.2, concerned with multifactorial diseases, the statement that they depend on variation at more than one locus may not be true. Thompson[53] reviewed evidence on the nature of polygenes and concluded the number of loci involved is about the same as the number of "major mutant" loci. The polygenes may be isoalleles, "normal wild-type alleles," of major mutant alleles. Polygenetic conditions could, therefore, be single mutations producing isoalleles and expressed by changes in epistasis caused thereby.

5. In Section I6.2 regarding estimates of increases in single-gene disorders (point mutation), a discussion of doubling dose is made and the article by Neel, Kato and Schull[54] is used to support the argument that the doubling dose in humans exceeds 140 rem in males and 1,000 rem in females. This is unfortunate since this estimate depends quite heavily on the assumptions made in the Epilog of the paper by Kato et al.[55], where some of the assumptions (page 369) are not referenced but are only presented as assertions. In view of the rapid developments in population genetics, perhaps these assumptions should be re-evaluated and adequately supported. Furthermore, Neel et al.[54] use a factor to compensate for the change from high dose rate to low dose rate; that is, a reduction factor of 3 or 4 in males and 20 in females. Use of these reduction factors will not be valid unless the mutation rates were measured at relatively high doses[48,50].

Perhaps more complete analysis of the data on the doubling dose and possible range of variation (3 R to 200 R) can be found in papers by Neel and Schull[56] and Parker[57]. These analyses are possibly more pertinent since Neel et al.[54] looked only at gametes which were lethal during the first 17 years of life. Estimates of doubling dose for other types of genetic doubling can be made from "Long-Term Worldwide Effects of Multiple Nuclear Weapons Detonations"[58]. Doubling of balanced chromosomal rearrangements occurred at about 55 rem and sex-chromosome aneuploidy at about 175 rem. Both values are within the 20-200 rem doubling range suggested by the BEIR Report. The disparity in values suggests that mutation rates may have to be considered on the basis of locus. This latter need is reinforced by the observation of Kohn and Melvold[59] that the "7-locus," "6-locus" and H-locus tests in mouse spermatogonium had different x-ray induced mutation rates - relative values of 60, 20 and 1 respectively.

The whole area of radiation-induced genetic effects is in a stage of flux, and changes in rates of mutation at any loci should have been carefully considered in the Reactor Safety Study.

F. Radiation Dose Causing Specific Clinical Effect

The Reactor Safety Study did not completely assess and assign appropriate SD values (radiation dose causing specific clinical effect). The Study should have specified SD values for respiratory impairment and hematopoietic failure expected after a reactor accident, if only in terms of ranges.

G. Other Biological Consequences

The Reactor Safety Study omitted some biological consequences of possible significance. To the extent that data are available, the following consequences should have been discussed:

(1) The synergistic and additive effects of other environmental pollutants for specific indicators of life shortening such as cancer, and

(2) A review of the extent of bioeffects anticipated in the terrestrial, aquatic and atmospheric ecosystems.

H. Underestimates of Risk

In regard to chronic or latent cancer fatalities, EPA holds the position that the linear, non-threshold hypothesis recommended by the NAS BEIR Committee is most appropriate. Therefore, EPA considers this model to represent the central estimate, as opposed to the definition in WASH-1400 whereby the central estimate is one in which a DREF of 0.2 is inserted to calculate health risks following a reactor accident. As a result, EPA suggests that WASH-1400 may underestimate the risks from some accident scenarios by as much as a factor of 5. In addition, however, the Agency feels that the Reactor Safety Study failed to recognize the importance of relative risks, thereby possibly introducing another factor of 2 error. The middle estimate of late somatic effects, then may be underestimated by a factor of 2-10.

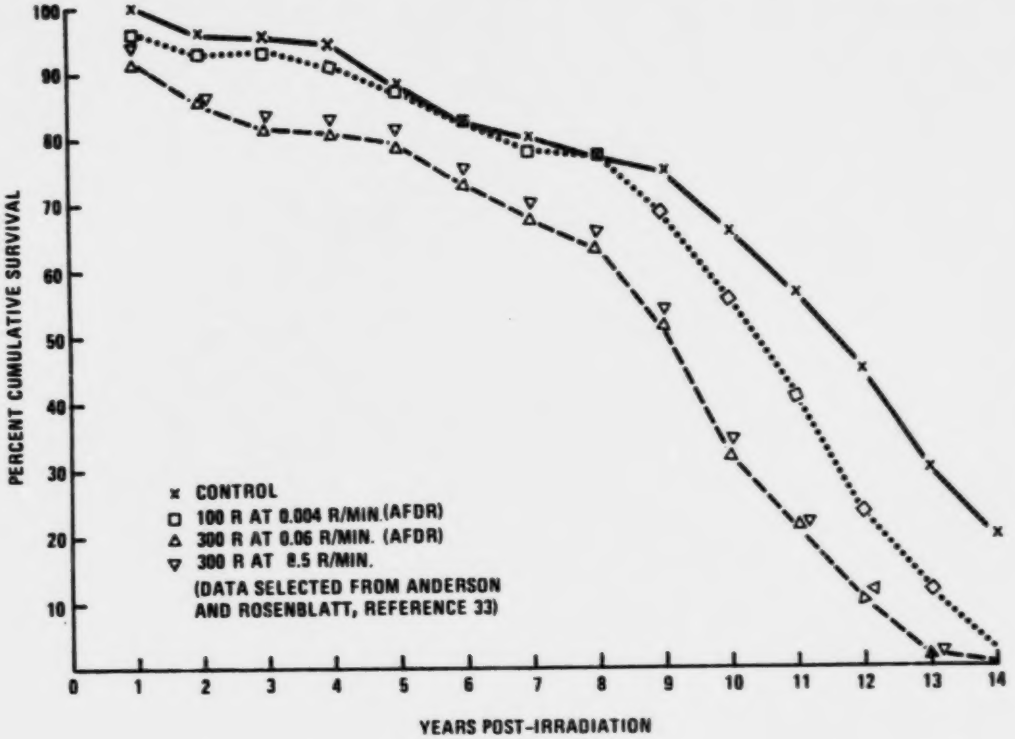

FIGURE 1. INFLUENCE OF RADIATION EXPOSURE ON LIFE-SHORTENING OF BEAGLES.

I. References

1. BAUM, J. W. Mutation theory of carcinogenesis and radiation protection standards. Sixth Annual Health Physics Society Symposium, Richland, Washington (1971) p.11.

2. BAUM, J. W. Population heterogenesity hypothesis on radiation induced cancer. Health Phys. 25:97-104. (1971)

3. BROWN, J. M. Linearity versus non-linearity of dose response for radiation carcinogenesis. Radiation Research (Abstract, in press: paper submitted to Radiation Research, October 3, 1975).

4. MOLE, R. H. Ionizing radiation as a carcinogen: practicable questions and academic pursuits. Brit. J. Radiol. 48:157-169. (1975)

5. MORGAN, L. Z. Reducing medical exposure to ionizing radiation. Amer. Indust. Hyg. Assoc. J. p. 358-368. (May 1975)

6. MODAN, B., D. BAIDATZ, H. MART, R. STEINITZ, and S. G. LENIN. Radiation-induced head and neck tumors. Lancet 7852:279 (February 1975)

7. SELTSER, R. and P. E. SARTWELL. Amer. J. Epidemiol. 81:2 (1965)

8. SHELLABARGER, D. J., V. P. BOND, E. P. CRONKITE, and G. APONTE. Relationship of dose of total body ^{60}Co radiation to incidence of mammary neoplasia in female rats. Radiation-induced cancer. International Atomic Energy Agency, Vienna, p. 161-172. (1969)

9. STEWART, A. and G. W. KNEALE. Radiation dose effects in relation to obstetric x-rays and childhood cancers. Lancet p. 1185-1188. (June 1970)

10. BOREK, C. and E. J. HALL. Transformation of mammalian cell vitro by low doses of x-rays. Nature 243:450-453. (1973)

11. BOREK, C. and E. J. HALL. Effect of split doses of x-rays neoplastic transformation of single cells. Nature 252:499-501. (1974)

12. WARD, B. C., J. R. CHILDRESS, G. L. JESSUP, and W. L. LAPPENBUSCH. Radiation sensitivity of the Chinese hamster, *Cricetulus griseus*, in relation to age. Radiat. Res. 51:599-607. (1972)

13. LAPPENBUSCH, W. L. and D. L. WILLIS. The effect of dimethyl sulphoxide on the radiation response of the rough-skinned newt (Taricha granulosa). Int. J. Radiat. Biol. 18(3):217-233. (1970)

14. ROSSI, H. H. and A. M. KELLERER. The validity of risk estimates of leukemia incidence based on Japanese data. Radiat. Res. 58:131-140. (1974)

15. KELLERER, A. M. and H. H. ROSSI. Theory of dual radiation action. Curr. Top. Radiat. Res. 8:85-158. (1972)

16. ROSSI, H. H. and A. M. KELLERER. Radiation carcinogenesis low doses. Science 175:200-202. (1972)

17. MAYS, C. W., R. D. LLOYD and J. H. MARSHALL. Late radiation effects: malignancy risk to humans from total body gamma-ray irradiation. Preprint: p. 417-428. (1975)

18. UPTON, A. C., M. L. RANDOLPH and J. W. CONKLIN. Late effects of fast neutrons and gamma-rays in mice as influenced by the dose of irradiation: induction of neoplasia. Radiat. Res. 41:467-491. (1970)

19. YUHAS, J. M. Recovery from radiation-carcinogenic injury to mouse ovary. Radiat. Res. 60:321-332. (1974)

20. MOLE, R. H. Patterns of response to whole-body irradiation: the effect of dose intensity and exposure time on duration of life and tumor production. Brit. J. Radiol. 32:497-501. (1959)

21. GRAHN, D., R. J. M. FRY and R. A. LEA. Analysis of survival and cause of death statistics for mice under single and duration of life gamma irradiation. Life Sciences and Space Research 10:175-186. (1972)

22. FINKEL, M. P. and B. O. BISKIS. Experimental induction of osteosarcomas. Progress in Tumor Research 10:72-111. (1968)

23. GIBSON, R., S. LILIENFELD, L. SCHUMAN, J. E. DOWE and J. J. LEVIN. Nat. Cancer Inst. 48:301. (1972)

24. CASARETT, G. W. Pathogenesis of radionuclide-induced tumors in Radionuclide Carcinogenesis. C. L. Sanders, R. H. Busch, J. E. Ballou and D. D. Mahluna. USAEC CONF-720505. (1973)

25. LAPPENBUSCH, W. L. and J. D. GILE. Effect of cadmium chloride on the radiation response of the adult rat. Radiat. Res. 62:313-322. (1975)

26. NATIONAL ACADEMY OF SCIENCES ADVISORY COMMITTEE ON BIOLOGICAL EFFECTS OF IONIZING RADIATION. The effects on populations of exposure to low levels of ionizing radiation. Washington, D. C. 20418 (1972)

27. U. S. ENVIRONMENTAL PROTECTION AGENCY. Environmental analysis of the uranium fuel cycle. Part III - nuclear fuel reprocessing. EPA-520/9-73-003-D. Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C. 20460 (1973)

28. HALFORD, R. M. The relation between juvenile cancer and obstetric radiography. Health Physics 28:153-156. (1975)

29. NEWCOMBE, H. B. and J. F. McGREGOR. Childhood cancer following obstetric radiography. Lancet p. 1151-1152. (November 20, 1971)

30. MOLE, R. H. Antenatal irradiation and childhood cancer: causation or coincidence? Brit. J. Cancer 30:199-208. (1974)

32. AINSWORTH, E. J., N. P. PAGE, J. F. TAYLOR, G. F. LEONG and E. T. STILL. Proc. of Symposium on Dose Rate in Mammalian Radiation Biology (CONF-680410). p. 4.1-4.21. University of Tennessee and U.S. Atomic Energy Commission. Oak Ridge, Tennessee. (1968)

31. LUSHBAUGH, C. C., COMAS, F., EDWARDS, C. L. and G. A. ANDREWS. Clinical evidence of dose rate effects in total-body irradiation in man. Proc. Of Symposium on Dose Rate in Manimalian Radiation Biology (CONF-680410) p. 17.1-17.25. Univ. of Tenn. and U.S.A.E.C. Oak Ridge, Tenn. (1968)

33. ANDERSON, A. C. and L. S. ROSENBLATT. The effect of whole-body x-irradiation on the median lifespan of female dogs (beagles). Radiat. Res. 39: 177-200. (1969)

34. CASARETT, G. W. and H. E. EDDY. Fractionation of dose in radiation-induced male sterility, in Dose Rate in Mammalian Radition Biology, D. G. Brown, R. G. Cragle and T. R. Noonan, eds. U.S. Atomic Energy Commission CONF-680410. National Technical Information Service. Springfield, Virginia. p. 14.1 to 14.10. (1968)

35. SHELLABARGER, C. J. and R. D. BROWN. Rat mammary neoplasia following Co irradiation at 0.03 R or 10 R per minute. Radiat. Res. 51. Abstract ED-3. (1972)

36. UPTON, A. C., M. L. RANDOLPH, and J. W. CONKLIN. Late effects of fast neutrons and gamma-rays in mice as influenced by the dose-rate of irradiation: induction of neoplasia. Radiat. Res. 41:467-491. (1970)

37. DONIACH, I. Effects including carcinogenesis of I^{131} and x-rays on the thyroid of experimental animals: A review. Health Physics 9: 1357-1362. (1963)

38. BEIERWALTES , W. H. and H. N. WAGNER, JR. Therapy of thyroid diseases with radioiodine. Principles of nuclear medicine. H. N. Wagner, Jr., W. B. Saunders Co., Philadelphia. p. 343-369. (1968)

39. MILLER, E. R., S. LINDSAY and M. W. DAILEY. Studies with radioiodine validity of histologic determination of iodine-131 radiation changes in the thyroid gland. Radiol. 65:384-393. (1955)

40. INGBAR, S. H. and K. A. WOEBER. The thyroid gland. Textbook of endocrinology. R. H. Williams, ed. W. B. Saunders, Co., Philadelphia. p. 105-286. (1968)

41. HAMILTON, P. and E. TOMPKINS. Personal communication (September 4) cited in Appendix II to Appendix VI of WASH-1400. (1975)

42. CONARD, R. A. A twenty-year review of medical findings in a Marshallese population accidentally exposed to radioactive fallout. BNL 50424. Brookhaven National Laboratory. Upton, N.Y. (1975)

43. DONIACH, I. Radiation biology. The thyroid. S. C. Werner and S. H. Ingbar. eds. Harper and Row, Publishers, New York. (1975)

44. JACKSON, G. L. Radioiodine therapy of thyrotoxicosis. Amer. J. Roentgenol. Radium Ther. Nucl. Med. 112:726-731. (1971)

45. DOLPHIN, G. W. and S. A. BEACH. The relationship between radiation dose delivered to the thyroids of children and the subsequent development of malignant tumors. Health Phys. 9:1385-1390. (1963)

46. COLE, R. Final report. Inhalation of Radioiodine from fallout: hazards and countermeasures. ESA-TR-72-01 (Appendix F, Ionizing Radiation: induction of thyroid pathology) DCPA Contract DAHC 20-70-C-0381, Defense Civil Preparedness Agency, Environmental Science Associates, Burlingame, Calif. (1972)

47. UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation Appendix C. The genetic risks of ionizing radiation. United Nations, New York. (1966)

48. ABRAHAMSON, S. IAEA International Symposium on Biological Effects of Low Level Radiation Pertinent to Protection of Man and His Environment. (1975)

49. CROW J., Presentation of the USA National Academy of Sciences report on the effects of ionizing radiation (BEIR Report). 2. Genetic Effects. Proceedings of the Third International Congress of the International Radiation Protection Association CONF-730907. W. S. Snyder, editor, U.S. Atomic Energy Commission, Oak Ridge. p. 37-42. (1974)

50. LYON, M. F., D. G. PAPWORTH and R. J. S. PHILLIPS. Dose-rate and mutation frequency after irradiation of mouse spermatogonia. Nature New Biol. 238:101-104. (1972)

51. LI, C. C. Human genetics priniciples and methods. (1962)

52. STERN, C. Principles of human genetics, 2nd edition. W. H. Freeman and Company, San Francisco. (1960)

53. THOMPSON, J. M., Jr. Quantitative variation on gene number. Nature 258:655-668. (1975)

54. NEEL, J. V., H. KATO, and W. J. SCHULL. Mortality in Children of Atomic Bomb Survivors and Controls. Genetics 76:311-326. (1974)

55. KATO, H., and W. J. SCHULL and H. V. NEEL. A cohort-type study of survival in the children of parents exposed to atomic bombings. Amer. J. Human Genetics 18:339-373. (1966)

56. NEEL, J. V.and W. J. SCHULL. The effect of exposure to the atomic bombs on pregnancy terminations in Hiroshima and Nagasaki. Publication No. 461. National Academy of Sciences - National Research Council. Washington, D.C. 20418 (1956)

57. PARKER, D. R. Statement on the genetic effects of ionizing radiation. Proposed Appendix I Hearings, Docket Number RM50-2. U.S. Atomic Energy Commission. Washington, D.C. 20545 (1972)

58. NATIONAL ACADEMY OF SCIENCES. Long-term world wide effects of multiple nuclear-weapons detonations. Genetic effects on humans. National Academy of Sciences - National Research Council. Washington, D.C. 20418 p. 203-212. (1975)

59. KOHN, H. I. and R. W. MELVOLD. Divergent x-ray-induced mutation rates in the mouse for H and "7-locus" groups of loci. Nature 259:209-210. (1976)

SECTION 3. OVERALL REVIEW

A. COMMENTS on the CONSEQUENCE CALCULATION DESCRIPTION

As revised in the final WASH-1400 report, Appendix VI, "Calculation of Reactor Accident Consequences," provides extensive information additions on some aspects of the calculational process. However, EPA's comment of November 27, 1974, is still applicable; that is, "Furthermore, the description of certain critical portions of the overall calculational process should be significantly expanded to permit a clear understanding of the relationships between the radioactive material releases, its dispersion, population distributions, and the resulting health effects." In our review of the draft WASH-1400 report, we noted the deficient description of the calculational process, but chose to give the Reactor Safety Study some benefit of doubt with regard to its adequacy, where the adequacy could not be discerned from the description. Since it has been necessary to revise the consequences evaluation so extensively in the final report, we believe that the revised analyses should be thoroughly documented. Toward this end, we recommend that the Reactor Safety Study group publish a technical report detailing the framework of the consequence model calculations. The report should give all the important analytical relationships and their interconnections as well as complete documentation of the computer program details, so that any compromises and limitations introduced in the programming are also made clear. Such a technical report is needed to show that the various parts of the calculations, some of which have been described in detail in Appendix VI, have been used in a coherent and self-consistent process to account comprehensively for the significant modes of exposure, applicable exposure areas, and relevant time periods. Without such a document, it is difficult to assess the overall realism and adequacy of the calculations. Such documentation should be provided in the near future, in addition to the 5-year update of the Reactor Safety Study suggested in the final report. The following comments will illustrate some of the deficiencies in the description of the consequence calculational process in the final report.

1. Appendix VI does not give the relation of the various models being used. The Introduction to Appendix VI states that the consequence model includes a "standard Gaussian dispersion model," and Section 13.2.1 indicates that "...isopleths for airborne radioactive material and for ground contamination..." were calculated, a process to which the Gaussian dispersion model lends itself. However, the description in Section 4, titled "Atmospheric Dispersion," indicates that the Gaussian dispersion model is used to estimate a measure of the exposure at only the centerpoint of each downwind sector-segment, which is then considered to be uniformly exposed over its rectangular area. The

relation of this calculation of exposures at a single row of segment centerpoints to the calculation of isopleths is not given in the report.

2. Appendix VI does not give a coherent picture of the way the duration of exposure for a population group is calculated. With regard to the duration of exposure, Section 4 states, "Initially the plume is treated as a simple ground-level release of 0.5 hour duration. It is then corrected for ... buoyant rise, differences in release duration..." and, "Transport speed, stability, and precipitation occurrence are updated by successive hourly weather observation as indicated." (It is believed the "as indicated" should be a reference to the statement in Section 5, "For all meteorological data for a particular site, the consequence model assumes that the condition that occurs at the site at a given hour also occurs simultaneously at all downwind locations to whatever distance the plume has traveled.") "Thus, the plume expands continuously by vertical and horizontal increments according to spatial increment length and location, hourly value of wind speed, stability class, and mixing depth."

Assuming, as was done in the model, that there is no major shift in wind direction, a release of 5 hours duration, for example, will be covering lengthwise (downwind) more than one spatial interval (given in Table VI 4-1), over more than 5 hours duration, as the plume also expands in the downwind direction. Plume expansion in the downwind direction is not considered, however, as indicated in Appendix A, "... neglects diffusion downwind compared to gross transport by the mean wind." It is not explained how the duration of exposure is calculated at a particular location, considering the hourly adjustments and the downwind extent of the plume. Perhaps from Sections 9 and 11.1.1.3, it may be inferred that a fraction of the population in each segment of an evacuation area is postulated to move radially away from the reactor at the selected effective evacuation speed (corresponding to that fraction of the population) until the radioactive plume catches them. The duration of exposure begins then; at the same time they turn to evacuate in the crosswind direction, requiring 4 hours to escape the area which has been contaminated (or is still being contaminated). They are irradiated by direct exposure to the plume for the duration of the release, or for 4 hours, whichever is less. Their dose commitment from inhaled radionuclides is determined on a similar basis. Their exposure to gamma radiation from the contaminated ground may be based on the amount of radioactive contamination present, both that which is accumulating on the ground during plume passage and that remaining after plume passage, but not for more than 4 hours total. All these modes of exposure (except from the already deposited and the already inhaled contamination) presumably were updated hourly according to the weather conditions, and the total exposure is the sum of the hourly exposures for the duration of plume passage, or 4 hours at most. Such a duration and summation of exposure for a particular population group may be inferred from various parts of the text, but other interpretations are possible. For instance, Section 9 may also be interpreted to mean that the exposed persons receive the "external dose from passing cloud" for the whole duration of cloud passage, regardless of whether it is less than 4 hours or more.

3. Similarly, the treatment of the plume width and the population exposed is not specified. Although it is indicated in Section 4 that the plume width is three sigma-y modified for the release duration, it also appears that the meteorological data and population data are based on 22.5 degree sectors. Perhaps a certain number of persons are calculated to be exposed within the modified three-sigma-y width, based on the average sector-segment population density in terms of persons per unit area; then the number of persons exposed in a sector segment will change with the hourly update in the meteorological data. If such a calculational scheme is being used, it should be explicity stated, rather than being left for speculation.

Due to the evacuation being underway, the segment populations will be different than originally, although how the changes are accounted for is not explained.

Under some conditions, the model plume is wider than a 22.5 degree sector; since the sector populations are not associated in the model with real neighboring sector populations, it should be stated that the sector population has been increased prorata for the additional width, if this has been done.

4. The description of the consequence model is not clear even in some of the aspects it covers, which is illustrated by the following:

(a) The modeling of the releases as puff or continuous releases; Section 2 of Appendix VI indicates: "These parameters, time and duration of release, represent the temporal behavior of the release in the dispersion model. They are used to model a 'puff' release from the calculations of release versus time presented in Appendix V," but Section 4 says, "Initially the plume is treated as a simple ground-level continuous release of 0.5 hour duration...," and gives an equation for a continuous release. Since a 0.5 hour duration is the shortest release duration listed (Appendix VI, Table VI 2-1), it appears that the calculation treats all releases using the continuous model, rather than a puff model.

(b) The treatment of the wind direction lacks clarity. The report does not state directly that it used a uniform distribution of wind "direction" to the composite site populations; rather, it says, "Actually, for the six composite sites representing the 68 actual reactor sites..., it was assumed that the wind direction distributions for such summations would approach uniformity."

(c) Similarly, it seems that the data in Tables VI 5-2A through VI 5-2G were included only as supporting background information, although they also could have been used to establish the probability of occurrence of a specific set of weather conditions at a site; their use was not specified.

(d) The treatment of precipitation duration in Section 6 of Appendix VI is confusing. In the case of continued rainfall in 6 consecutive hours, for example, it is not clear whether the model would employ 3 hours rainfall or 5 hours.

(e) Again, in Section 6, it is stated that, "Dry deposition is assumed to proceed at all times, and variations in deposition velocity because of precipitation, surface wetting, vegetative cover, desorption, etc. are ignored. The consequence model uses a deposition velocity of 10^{-2}m/sec, with a possible range of $10^{-3}$to 10^{-1} m/sec...," but there is no explanation of how the possible range is used.

(f) Section 7 introduces "scavenging coefficients" and "removal times" but does not explain definitively what they are or how they were used.

(g) Section 13.2.1 states "For each release category stated in Table VI 2-1, each of these 90 weather samples is used to calculate isopleths for airborne radioactive material and for ground contamination." How these isopleths are used in the calculational process is not indicated, except for the statement, "...the interaction of each of these 90 isopleths with each of the 16 sectors is calculated." The use of isopleths does not seem to match the rest of the model.

(h) On page 8-4 there is discussed a correction factor, which is applied to account for the facts that the cloud is finite and the receptor need not be on the centerline of the cloud; it should be stated in addition that the receptor is then assumed to be on the ground directly under the centerline of the cloud, and the exposure for such a receptor is applied uniformly to all exposed persons in that segment within the three sigma-y plume width.

B. Corrections or Information Additions Needed (Appendix VI)

1. Certain of the accident consequences depend to a large extent on the size of the radioactive particles. Particles 15 micrometers (μm) in diameter or more will tend to deposit more quickly. Exposures from inhalation are greatly dependent on particle size. Appendix VI, Section 6.3.1 mentions, "... 1-micron-diameter aerosols (particles and vapors)...." It appears (but is not stated) that this size was assumed for the calculation of consequences. Appendix K to Appendix VI states "...whereas the aerosols that would be expected to be released from a reactor core meltdown would be at most a few microns in diameter." Appendix H to Appendix VII refers to particles of sizes 0.02 to 0.1 μm of density 5 grams/cubic centimeter (g/cc). Except for the discussion of the steam-explosion case (Section 1.4), the rest of Appendix VII discusses only particles in the range 10 μm to 15 μm. Concerning the steam explosion case, Section 1.4 does not mention sizes but does indicate that fission products would be released through vaporization. However, there is nothing in Appendix VII, or elsewhere, which traces the transition between these particle sizes and the "... 1-micron-diameter aerosols (particles and vapors)...." There should be a discussion of the size of released particles, of the factors which change the size distribution, and of the size distributions to which the public might be exposed.

2. With regard to the resuspension discussed in Appendix VI, Section 8 and Appendix E, it should be noted that the "resuspension factor" discussed may be correctly applied to the central portion of a contaminated area which is so large that by the time air from outside the contaminated zone travels to the center, it has acquired an equilibrium amount of contamination. This will be of little importance when health effects are being estimated by use of a linear, non-threshold relation to exposure, since it may be expected that people downwind from the contaminated area will also be exposed by the resuspended contamination and thus may compensate for those in the contaminated area whose exposure is diluted by incoming uncontaminated air. This would not apply when health effects are being estimated using a dose-rate or dose-magnitude dependence, unless all exposures happen to be within the same range. It is not stated whether consideration was given to resuspension exposures other than in the case where equilibrium is reached and all exposures are uniform.

3. It appears from the data presented in Appendix E of Appendix VI, in Table VI E-3, that there is an initial larger resuspension rate, characterized by a resuspension factor of perhaps 10^{-2} to 10^{-4} with a half-life in the range of 30 to 90 days. It is not clear

that this has been considered in assessing exposures and re-entry or relocation requirements.

4. Section 8 of Appendix VI begins:

> "The release of radioactive materials to the environment constitutes a potential hazard to man. The word 'potential' is used to stress the point that, for all practical purposes, man's concern about radioactive materials in the environment exists primarily when the material is in sufficient concentrations to impose a radiological burden higher than some value which the particular individual finds acceptable in light of the exposure he receives from natural sources."

The second sentence needs to be deleted. Hazard is quite different from being concerned. Man can easily be unconcerned due to ignorance or misinformation. Since WASH-1400 (and Section 8) deals with a range of radiation exposures which includes exposures lethal within a few months, this statement is inappropriate.

5. Appendix VI, Table VI 8-4 needs revision in that columns for shorter periods, e.g., 0 to 1 year, are needed, whereas the columns for 0 to 20 years and longer periods are superfluous for all the radionuclides listed, with the exception of strontium-90.

6. With regard to the use of firehosing for decontamination, there is an inconsistency between Section 11.2.2.3 which states:

> "As discussed in Appendix K, present experimental evidence is not adequate to support any assumptions on the effectiveness of wet decontamination (i.e., firehosing) for the small aerosol particles released during the reactor accident. Therefore, the removal of contaminated surfaces is the only decontamination procedure postulated by the study for hard surfaces."

and Section 12.4.1.2 which says:

> "The costs of decontaminating developed property are estimated on the assumption that two alternative methods would be used, depending on the degree of decontamination required to meet the radiation exposure standards. If a decontamination factor of 2 would suffice (50% reduction in contamination), the method would consist of replacing lawns and firehosing roofs and paving. If a decontamination factor of 20 were required

(95% reduction in contamination), lawns, paving and roofing would be replaced."

7. Section 12 of Appendix VI appears to have omitted the costs of decontamination and replacement of household goods.

8. Only in very rare instances does WASH-1400 provide any absolute dose values. One such is the statement in Section 9.2.3.7 of Appendix VI: "Since dose rates in excess of 20 rads per day could only be experienced within a mile or so of the reactor in the event of the largest release...." In another instance, in Section 9.2.2.1, it is stated, "In the event of the worst calculated accident (corresponding to a probability of about 10^{-9} per reactor year), the number of people receiving a dose in the range of 350 to 550 rads would be about 5,000; none would receive a dose above 550 rads." Nowhere in WASH-1400 are the absolute exposures of this or any other specific case detailed, although some relative doses are provided. Thus, it is not possible to assess the accuracy of the consequence estimates by comparison to calculations of radiation exposures.

   It is noteworthy that in no instance does the WASH-1400 scenario call for heroic treatment using their health effects evaluation, i.e., heroic treatment for those who receive more than 550 rads. A better evaluation of the health effects would indicate that the group receiving 350 to 550 rads should receive such treatment, if available.

9. Section 13.3.2 of Appendix VI states, "Figure VI 13-26 shows the conditional probability for an individual of dying from latent cancer as a function of distance from a reactor given the PWR-1A or PWR-1B releases. The probability of latent cancer fatalities is relatively constant out to about 100 miles...." Although this Figure VI 13-26 has been replaced by the recently issued Errata Sheets, the accompanying text in Section 13.3.2 has not been corrected accordingly. The new Figure VI 13-26 shows more realistically that the probability drops off rather rapidly from about one mile outward. However, it indicates that the greatest individual probability of dying from latent cancer is 0.008; this value appears to be quite low and should be explained.

10. Section 13.4 of Appendix VI states, in essence, that a 9 percent increase in fatal cancers (from the largest calculated accident) over a period of 30 years, "... would probably not be statistically detectable because of the normally large variation in the rate." The projected increase from the largest calculated accident, even in the total population of the United States where it would amount to about 0.4 percent increase, might well be detectable in the 30 year average. Furthermore, the statement

assumes that no one is keeping track of the irradiated population. Considering the attention that has been devoted to study of atomic bomb victims, it is inconceivable that a study would not be instituted to evaluate the effects of such a large accidental radiation release. Furthermore, it is not likely that the irradiated population would ignore the health implication to themselves. On the contrary, there would more likely be massive class-action liability suits, supported by specific medical investigations and group studies.

11. The estimation of the overall risk of severe accidents is the important result of the Reactor Safety Study; assessment of the worst calculated accident is of little value if it is isolated and not put in the context of the spectrum of accidents and their probabilities, such as in Figure 5-3 of the Main Report. The reason is that, as shown in the discussion in Section 13.2.1 of Appendix VI, the probability of experiencing the largest consequence on a per-reactor-year basis can be changed as desired, over a large range. In the example given, it can be changed by changing the number of population distributions ("sectors"), or it can be changed by changing the number of weather samples. However, the worst calculated accident attracts attention.

The information in WASH-1400 about the worst calculated accident does not seem to be consistent. Table 5-4 in the Main Report indicates, for an accident having a probability of one in a billion per reactor year, that 3,300 early fatalities would be expected. Section 9.2.2.1 of Appendix VI states "In the event of the worst calculated accident (corresponding to a probability of about 10^{-9} per reactor year), the number of people receiving a dose in the range of 350 to 550 rads would be about 5,000; none would receive a dose above 550 rads." It also states that the number of early fatalities is estimated on the basis of Curve B in Figure VI 9-1. For this information to be consistent, it seems that all 5,000 must receive a dose close to 550 rads, rather than a distribution over the range 350 to 550 rads. A better explanation appears to be needed.

12. There are a number of other inconsistencies which, most probably, can be clarified with a little additional explanation. Figures VI 13-23 and VI 13-24 show curves of conditional probabilities of early death which have shapes that appear reasonable in view of other experience in calculating radiation exposures. Figure VI 13-7 seems to be in conflict with these, since it shows a mortality probability of 1.0 for some distance from the reactor, as opposed to a maximum near 0.1 in Figure VI 13-23 and 0.005 in Figure VI 13-24. It is noted that different accidents may be the subject of these figures; while Figures VI 13-23, VI 13-24, and VI 13-26 are specified as being for PWR-1A or PWR-1B releases, the accident case for Figure VI 13-7 is not

identified, although the discussion of Figures VI 13-5,6,-8,-9 identifies them as the consequences of a large cold release, which may or may not be PWR-1A. Whether any of these accident cases is the same as the one in a billion event which is the subject of Table 5-4 in the Main Report or the same as the "worst calculated accident" referenced in Section 9.2.2.1 of Appendix VI, is not clear. The use of different population distributions for different cases should be made clear also; some are for 100 persons per square mile whereas the others may be for a "worst case" population, which should be specified quantitatively.

13. The following are problems in Appendix VI that may be of an editorial nature:

(a) Page 3-1, paragraph 3, line 7 - 880 apparently should be 8,800, if the choice of burnup is intended to be somewhat conservative.

(b) Page 4-2, The correction factor for air concentration should have a minus sign in front of the exponent. (See equation 5.12, Workbook of Atomspheric Dispersion Estimates, D. B. Turner, PHS No. 999-AP-26, 1967.)

(c) Page 9-34, Table VI 9-5 needs additional explanation, in footnotes or revision of its title.

(d) Page 13-34, Table 13-6 - The manner of calculating the average values of maximum health consequences should be explained.

(e) Page C-1, equation VI C-2 - The constant term appears to be missing from the equation.

(f) Page D-22, equation for R(t) - The first exponential term is incomplete.

(g) Page D-26 - The masses given for the three groups of organs and tissues classified by Ostwald coefficients add up to 60 kg, not 70 kg. The difference should be explained.

(h) APPENDIX K - This appendix should include a table of limits of surface contamination and similar "rules of thumb" such as given in Section 3 of Technical Report Series No. 152, Evaluation of Radiation Emergencies and Accidents, by E. J. Valario, published by IAEA in 1974.

C. Actions to Mitigate Radiation Exposures

In conformance with a Federal Register notice of Interagency Responsibilities for Nuclear Reactor Incident Response Planning dated

December 24, 1975, the U.S. Environmental Protection Agency is responsible for providing practical guidance to State, local, and other officials on criteria to use in planning protective actions for radiological emergencies that could present a hazard to the public. Initial guidance, relative to exposure to airborne radioactive material, was issued to the public in September 1975. Further guidance dealing with protection from contaminated foodstuffs and water and for protection from exposure to radioactive material deposited on property or equipment is under development and will be issued when it becomes available.

In view of our responsibilities and interest in this matter, we have taken a close look at those parts of the Reactor Safety Study which deal with protective actions which would be taken to reduce the health impact of any radionuclide release resulting from a nuclear reactor accident. We have found that the discussion of actions which would be taken to mitigate the consequences of long-term exposure due to accidental radionuclide releases is generally in agreement with studies being made toward development of EPA guidance, and that pending the issuance of EPA guidance dealing with protection from exposure to contaminated media, the reliance by the Reactor Safety Study on recommendations of the Federal Radiation Council and the Medical Research Council of Great Britain regarding long-term exposure dose criteria for external radiation and ingestion via milk and other pathways appears to be reasonable.

However, we are not in such good agreement with the model which the Study employed to simulate evacuation of people in the vicinity of the reactor during the emergency phase (within a short time) of the accident. In our view, the implementation of a protective action, such as evacuation, should be directly related to the severity of the projected reactor accident health consequences. Considering the projected offsite doses to be indicative of the potential health impact of a radionuclide release, if evacuation is chosen as a protective action, then the dimensions of the evacuation area should be determined by the projected offsite doses or a dose isopleth corresponding to some predetermined acceptable level of risk. The dose levels at which evacuation or shelter should be considered have been recommended by the EPA in its guidance issued in September 1975, dealing with exposure to airborne radioactive material. However, it appears that in the evacuation model chosen by the Reactor Safety Study, the dimensions of the area which would be evacuated are fixed and do not depend on the reactor accident severity, other than the condition indicated in Section 12.2.1 of Appendix VI that a core meltdown is assumed. Thus, it appears that people are assumed to be evacuated from a large area even though evacuation of only the low population zone might be necessary. On the other hand, it appears that in the most severe accidents, people who might require protection beyond the present evacuation area are not evacuated.

The following are some specific comments pertaining to the modeling of actions to mitigate radiation exposures in the Reactor Safety Study.

1. In section 11.1.1.2, it is acknowledged that approximately 5 percent of the people might be expected to refuse to evacuate and that this minority was not explicitly treated in the reactor accident consequence assessment. Since the radiological impact of a radionuclide release on these people might not be ameliorated by evacuation, nor by medical treatment, their contribution to the total population early health effects could be appreciably greater than their relative proportion of the exposed population.

2. Apparently, the Reactor Safety Study considered only situations in which the population in something like the "keyhole" area (Figure VI 11-2) would always be evacuated regardless of projected reactor core melt consequences. If the evacuation decision were based on a short-term exposure Protective Action Guide (PAG), such as EPA's recommended PAG's, an incentive would exist to first evacuate the people who live closest to the reactor and to assign a lower evacuation priority to residents further away from the plant. Since this response could possibly result in fewer acute health effects, future efforts should analyze the potential effects of such an option on overall reactor accident consequences.

3. It appears from WASH-1400 that evacuation more extensive than the 25-mile-radius keyhole area, shown in Figure VI 11-2, was never used in the consequence calculations, although dose factors were developed for it, i.e., exposure to gamma rays from ground contamination for 24 hours, as indicated in Section 11.3.4. It appears that discussion of such events is only background material.

4. While we recognize the generic nature of the Reactor Safety Study, we think that greater consideration should have been given to the effect of site specific parameters on the accident consequence model. For example, no attempt appears to have been made to take into account the actual status of development of State radiological emergency response plans at individual reactor sites. It is assumed in Section 12.2.1 of Appendix VI, that emergency plans exist, but this may refer only to the plans of the nuclear power plant operator. Likewise, site specific parameters which might affect the speed of evacuation have not been evaluated. An assessment of the range of consequences due to the differences in site specific circumstances would have made an informative contribution to the report. As it is, even the variation in population distributions has been omitted; only an overall average population density is given. Thus, it is

difficult to judge even the difference in consequences between the maximum population and the average. Some compensation for these weaknesses is made by the inclusion of ranges of consequences, but the parametric effect of various factors such as these is not clearly presented.

5. The choice in Section 11.2.1.2 of lower dose criteria for relocation of people in a rural area than for those who live in an urban area is debatable. It is not clear that such an approach would be workable. It is likely that asking some population groups to accept greater radiation exposure because of where they live would not be well received.

6. Section 11 of Appendix VI discusses protective measures for mitigation of radiation exposure. The distinction in Section 11 between evacuation and relocation appears to be unrealistic in that, although an evacuation might be initiated immediately, it may not be reasonable to return people to their homes if the homes are so highly contaminated that long-term relocation is deemed necessary. The people would only receive unnecessary additional radiation exposure, and might tend to spread contamination by bringing contaminated belongings with them in relocating.

7. In Appendix J of Appendix VI, data from the EPA report Evacuation Risks - An Evaluation have been used to construct predictive models for future evacuations. The analysis centers on evacuation speed and has been done both for single classes of events and for a general evacuation. Two approaches have been used. The first is to determine an underlying probability distribution for evacuation speeds. The second is to relate speed to other factors through regression analysis. For either approach, the choice of data is critical and the lack of information on data selection criteria is a major flaw in the report.

The first step in the selection process is to determine classes of events with enough data for individual analysis. The three classes chosen (floods, hurricanes and transportation accidents) are clearly the only ones with sufficient data for analysis as individual classes. However, the criteria for selecting particular events within the chosen classes are not clear. Using the data categories shown in Tables VI J-1, through VI J-3 as a basis for inclusion, there are five floods (No. 4a, 4b, 5, 29 and 36a) and one hurricane (No. 48) that should have been included. In the regression analysis, the total area evacuated is one of the independent variables used, and yet for events No.30a and 30b (Table VI J-2) that information is not available and there is no indication as to whether those events were included or excluded from the regression analysis. Thus, the conclusions drawn in the report for floods and hurricanes could be incorrect due to improper data selection. It is noted that Section 11.1.1.3 indicates that transportation accidents were used as the basis for the model for evacuations due to reactor accidents.

To do the modeling for the general case, the data set seems to be made up of only the three largest classes of events. Unless the general model is only intended for floods, hurricanes and transportation accidents, other events with sufficient data should have been included. The restrictions imposed through the selection of data have thus made the general or "combined" model not truly general.

While data selection is the most critical problem, there are also several points in the statistical analysis which need either clarification or correction. The first model developed is one which assumes an underlying distribution of evacuation speeds. The object of the analysis is to determine which distribution best describes the data. As the analysis has been done here, the only distribution used is the log-normal. A test of the data by means of the "Lilliefors test" has shown consistency with the log-normal hypothesis. It should be noted that, especially for the single class analysis, the number of data points is quite small, and the ability of the Lilliefors test to reject log-normality when the data are in reality from another distribution is quite low for small sample sizes.

The graphs in Figure VI J-1 through VI J-3 show that the data, while generally following a linear trend, are not close enough to the hypothesized line to warrant a claim of log-normality from a graphical method. Therefore, any conclusions based on the assumption of log-normality should be drawn with caution in this case.

It should also be noted that the Lilliefors test assumes the use of unbiased estimates for parameters. The maximum likelihood estimate for the variance is biased and, therefore, should be modified. If this modification has been done, such was not stated in the report.

For the second model, an attempt has been made to relate speed to other factors, such as distance traveled, size of area evacuated and the number of people evacuated. The results of this analysis are that speed is related to distance, but not to the other factors. This holds for both the single class analysis and the combined data.

The combining of data has been justified on two statistical grounds. The first is that the confidence intervals for the coefficients overlap. Although the large amount of overlap does indicate that the coefficients are probably not significantly different, this procedure is not a valid statistical test for equality. The second test involving an "F statistic" needs to be clarified and referenced to determine validity. There are standard procedures for determining the equality of regression equations, in Brownlee[3] (pp. 376-390) and in Draper and Smith[4] (pp. 74-77).

On page J-5 of Appendix J, to Appendix VI, the confidence interval given for predicting "v" is incorrect. There should be at least one additional term involving "d" in the exponent. For discussions of confidence intervals for predicted values, see Brownlee[5] or Draper and Smith[6].

It should be emphasized that the combining of data does not need to be justified on statistical grounds. The objective of combining data in this instance is to get a better indication of the general situation. Therefore, the data for different classes may follow different trends. The only valid test is whether or not the combined data can be described adequately by a single regression line.

8. The discussion of reduction of early mortality on page 13-34 of Appendix VI is confusing. It is not clear whether the early mortality probability at 1.2 miles per hour (mph) is a factor of 10 lower than at 0 mph or at no evacuation at all. For a given population distribution around a reactor site, the average probability of individual early mortality should be proportional to the number of early mortalities. Yet, according to Table VI 13-6, the ratio of early mortalities at 0 mph and 1.2 mph is 6,200/2,300 = 2.7. Thus, the factor of 10 would seem to be a comparison between 1.2 mph evacuation and no evacuation. However, the unqualified parenthetical information implies that, by providing more shielding, the no-evacuation scenario provides better protection overall than the 0 mph evacuation case.

D. Corrections or Information Additions Needed (other than in Appendix VI)

The following are comments on the parts of WASH-1400 other than Appendix VI.

1. Even though the statement is made in the Executive Summary, page 1, footnote 1, that data for long-term health effects are not available for non-nuclear accidents, we believe that the long-term

health effects for nuclear accidents should be indicated in the footnote to present the risks frankly.

2. In Section 2 of the Executive Summary. "Questions and Answers About the Study," a table presents the most likely consequences of a coremelt accident, and shows that they are small. We believe that this aspect of the results of the Study deserves more stress. It should be emphasized that industrial accidents will happen at nuclear power plants, e.g., the Browns Ferry fire, but that in the vast majority of cases, the consequences to the public will be minor or nil, with the exception of indirect expenses such as that due to lost electricity production.

3. On page 49 of the Main Report, it is stated:

> "The probability associated with a specific consequence is determined by combining the probabilities of the individual input parameters, i.e., by multiplying Prelease x Pweather x Ppopulation. In determining the consequence probability in this way, it is necessary to assure the probabilities are reasonably independent. It is difficult to visualize that the accident and the population densities can significantly affect one another. It seems equally reasonable to assume that the population and the weather have no strong dependency, since the frequency distributions have been obtained by combining actual meteorological and demographic data applicable to a large number of sites."

The report fails to establish the validity of the independence of meteorological conditions and population distributions. It appears that any such independence is an artifact of the construction of composite sites. Indeed, the text of Appendix VI, Section 5, argues against such independence at any specific site:

> "Figures VI 5-1a through g show wind transport vector (direction towards which wind blows) roses for each site for the hourly data averaged over the year. Comparing the different wind-transport roses points out the influence of the individual site topography on the average wind flow. Site A shows the influence of the river valley, with a predominant flow toward the south-southwest and a

> secondary maximum up-valley toward the north-northwest. The valley curves at the site location, which explains the nonalignment of the up-and down-valley maxima. Site D on the flat plain has the most uniform (quasi-isotropic) direction distributions. Site E has a remarkable maximum direction frequency at southwest, due to the presence of a small hill to the northwest and a gully cutting through the elevated coastal plain adjacent to the hill, which effectively channels the nighttime land breeze. The site G valley is quite level near the site but rises to several thousand feet on the southeast side at the Blue Ridge-Smokey Mountains complex. Thus the up-and down-valley flow is quite dominant. Actually, for the six composite sites representing the 68 actual reactor sites (described in section 10), it was assumed that the wind direction distribution for such summations would approach uniformity. This assumption is based on the fact that local topographic features which may strongly influence surface winds are generally randomly oriented when taken over such a large number of individual locations."

This quoted material, down through the word "Actually," was deleted by the Errata Sheet issued in May 1976. The referenced figures appeared only in the limited first printing of WASH-1400. Although deleted, the quoted material is factual and serves to substantiate the point that there are grounds for believing that the distribution of meteorological conditions and the population distribution may not be independent as assumed, due to their mutual dependence at any individual site on the local geographic and topographic features.

Local geographic and topographic features which influence wind patterns in the vicinity of a power plant site are also likely to have an influence on the population distribution. For example, neighboring towns and cities are likely to be in the valley which channels the winds. Towns and cities are also strung along the sea coasts which are subject to daily on-shore and off-shore breezes. Such distributions argue against the suggested independence, especially with regard to nearby locations where consequences may be sufficiently severe to produce acute health effects. Perhaps the realism of associating the meteorological conditions at a specific site with its own population distribution is unnecessary for the determination of average, overall risk; it is not obvious, however, and should be established.

4. Section 5 of the Main Report of WASH-1400 states, "In the largest accident predicted in the study, the 1500 latent cancer fatalities would be distributed over approximately 10 million people." Nowhere is it made clear how the figure of 10 million people was determined; whether that is the population within a 22.5 degree sector in the downwind direction within 500 miles, or whether it was determined in some other fashion. It would seem that there must be sectors of that size which would contain appreciably more than 10 million people, for example along the Washington-to-Boston corridor. On the other hand, krypton-85 and a few other radionuclides would contribute to world-wide exposures if released, involving a much larger population. The criterion for determining the affected population is of interest, since the consequences of reactor accidents are compared to the normal incidence of cancer fatalities, thyroid nodules, and genetic effects, apparently in a population of 10 million (Tables 5-5 and 5-8). The tables should be corrected to acknowledge, if it is indeed correct, that this is the population for which the normal incidence figures are applicable, and that the more probable accidents would affect a much smaller population to an equivalent extent, i.e., comparison to the normal incidence from a smaller population would be applicable.

5. In Section 5 of the Main Report, the figures which present results, e.g., Figures 5-10 through 5-16, have footnotes stating estimated uncertainties, as was done in draft WASH-1400. It is difficult to give credence to the estimated uncertainties, however, since in many segments of the figures the change from the draft WASH-1400 to the final WASH-1400 is greater than the uncertainty estimated in either. For example, the probability per year for 20 or fewer early fatalities (Figure 5-10, for 100 reactors) has been decreased by more than a factor of 10; this is a large change compared to the estimated uncertainties, which are factors of 1/3 (draft) and 5 (final). The new Appendix XI, on pages XI 1-2 and 1-3, discusses changes made, most of them increasing the consequences or probabilities. There is no explanation provided, however, for the large changes indicated in these figures. Instead, it asserts to the contrary:

> "In general, the potential consequences predicted in the final report have increased over those predicted in the draft report. All predicted consequences in the final report, except one, were within the factors of 1/3 and 3 error bands of the values predicted in the draft report. The predicted average value of latent cancers increased by a factor of about 7, due principally to the error made in the weathering half life that was assigned for cesium decay in the draft report. This effect also increased the land area needing decontamination by 5 and that in which relocation is required

> by 10. Early illnesses were calculated on an organ by organ basis which increased the magnitude by a factor of 6. The rest of the changes were within the confidence bounds of the predictions in the draft report."

and further:

> "Although the probabilities predicted for the various accident sequences have changed in some details, the overall predicted probability of accidents did not change significantly."

Comparison of Figure 5-12 with the corresponding figure in draft WASH-1400 shows, rather than the increase as in the above quotation, a decrease in latent cancer fatalities by about one-half for any given probability per year, over a large range of probabilities.

Similarly, in large parts of Figures 5-11 and 5-13, the change for a given probability per year is much greater than a factor of 3.

In Table 1-1 of the Executive Summary, the "individual chance per year" from nuclear reactor accidents has also decreased by much more than a factor of 3.

6. In the Main Report, Section 6.4.9, it is stated that "The evacuation model used is based upon one developed by the Environmental Protection Agency (Ref.8)." To be correct, this statement should be changed to read: "... based upon data collected by ...," since the reference does not include an evacuation model.

7. We believe that the last sentence of Item a, in the last paragraph of page 72 of the Main Report should be rewritten to read, "This suggests that the likelihood of an accident which affects the public is less than 10^{-3} per reactor-year."

8. It is not clear whether cost data and cost estimates, in the Main Report, for property damage for the non-nuclear and nuclear accidents are expressed on a consistent basis such as 1975 dollars. We believe that historic events (for example, the 1906 San Francisco earthquake and fire) should be costed using the same calendar year dollar basis used to estimate the costs of predicted future events (such as serious nuclear plant accidents). If a conversion to the same calendar year dollar basis is made, it should also be explained.

9. It appears that the last sentence of the first paragraph of Section 6.4.3 of the Main Report, should read, "In the United States single family dwellings represent about 40 percent of the

value of all capital property and, therefore, the total capital property damage could easily be a factor of 2 larger." If the above does not accurately express the intended meaning of that sentence, then it appears that damage to commercial, industrial, governmental, etc., capital property due to earthquakes has not been considered.

10. In Appendix XI, Section 3.2 and its Attachment 1, "Analysis of the Browns Ferry Fire," should have been written to include a short chronology of the events that actually occurred, starting with the ignition by candle flame. From the reports of the fire, it appears that a reasonable choice of phases would have selected phase 1 as the period from the start of the fire until 5.5 hours later when the last 4 relief valves became inoperable; phase 2 as the 4 hour period during which all relief valves were inoperable; and phase 3 as the period beginning when some relief valves were restored to service. Figure XI 3-8 (in the second printing of final WASH-1400) clearly shows the boundary between phases 2 and 3 at some time roughly in the middle of the period during which all relief valves were inoperable. The selection of this time is not explained, but it appears to have been selected as the boundary between periods of higher and lower probability of the incident proceeding to core meltdown. The legend of Figure XI 3-8 and the text describe the phases in a confusing manner. The legend of Figure XI 3-8 identifies "Phase 2 of the fire, during which the controls for the reactor vessel relief valves were or could have been failed...," when in fact there was, by various reports, a period beginning at 5.5 hours during which all eleven relief valves were inoperable. Similarly, on page XI 3-57, Attachment 1 states, "During phase 2, had the central system for all eleven relief valves been inoperable, the single operating control rod drive (CRD) pump would have been incapable of maintaining an adequate level of water in the core at high pressures," which was actually the condition while all relief valves were inoperable, as acknowledged on pages XI 3-59 and XI 3-60.

Perhaps Figure XI 3-8 incorrectly indicates the time at which phase 3 begins. In the "Evaluation of Phase 3 Logic Tree," the text says: "The analysis is similar to that used for times shorter than 5.5 hours. The event symbols are shown on Fig. 2, which depicts the logic for times longer than 5.5 hours." Similarly, Figures 1 and 2 showing the logic trees are clearly labeled "... for Time Less than 5.5 Hours After Fire Start," and "... for Time Greater Than 5.5 Hours After Fire Start." These all indicate that the 5.5 hour point would have been a good time to end one phase and begin another.

11. The discussion of "Other Possible High-Pressure Makeup Sources" on page XI 3-57 needs additional explanation to the

effect that an additional control rod drive (CRD) pump would not double the existing CRD flow. Otherwise, it would seem that the use of an additional CRD pump would be as effective as closure of the bypass line in the CRD system, discussed in the subsequent paragraph.

12. Some further qualification is needed of the selected probability of fire occurrence. On page XI 3-55, it is stated: "Since approximately 200 reactor-years of experience exist, the probability of a fire occurrence is estimated to be 1/200, or 5×10^{-3} per reactor-year." Reports relating to the Browns Ferry incident list a number of previous fire occurrences; they were simply of lesser safety significance. Noteworthy was the fire at the Swiss Muehleberg nuclear power plant (July 28, 1971) which also burned many cables and delayed operation of the plant about a year. Admittedly, this fire was outside the United States data base. However, there have been a number of other fires at nuclear power plants which this selection of the probability of fire occurrence appears to ignore.

13. Although the Browns Ferry fire analysis is considered for the fire as it occurred, WASH-1400 also looks at other possible failures which could have made the results worse. One point not discussed is whether further burning of other cables within the two rooms that were the scene of the fire could, by itself, have led to the additional equipment failures necessary for core melt.

14. There are some discrepancies in the numbers quoted for the likelihood of core melt due to a fire like the Browns Ferry fire. On page XI 3-41, it is indicated that the likelihood is 5×10^{-6} per reactor year, or just 10 percent of the 5×10^{-5} per reactor year total probability of coremelt given in the preceeding paragraph. On page XI 3-52, however, a figure of 20 percent is given, which is in agreement with the probability of core melt of 1.0×10^{-5} per reactor year given on page XI 3-59.

15. The statement on page XI 3-51 that "... the analysis for plant No. 1 bounds the probability of core melt at Browns Ferry as a result of the fire...," does not appear to be correct, because the risk from damage to Unit No.2 (no matter how small) was in addition to the risk from damage to Unit No. 1. Further, the Browns Ferry fire demonstrated the possibility of simultaneous damage at both units, in which case the sharing of redundant equipment between units (e.g., spare control rod drive pumps) means that it is not available to both units simultaneously in case it is needed and, thus, the risk when both units are involved is greater than the sum of the risks for separate, non-simultaneous incidents at each unit.

E. Review of Response to EPA Comments on Draft WASH-1400

The new Appendix XI, "Analysis of Comments on the Draft WASH-1400 Report" contains responses to the majority of EPA's comments, including complete coverage of EPA's comments of August 15, 1975. However, not all of EPA's comments of November 27, 1974, were responded to, nor was a response made to all the comments in the report by EPA's contractor, Intermountain Technologies Inc. (ITI). For an analysis of the response to ITI's comments, refer to ITI's supplementary report, "A Review of the Final Report Reactor Safety Study (WASH-1400)," April 1976 (Section 4 of this report). Many of EPA's comments of August 15, 1975, were based on ITI's report, and, thus, a response that is inadequate with regard to the comment in ITI's report is likewise inadequate with regard to EPA's parallel comment. However, the response to the remainder of EPA's comments of August 15, 1975, is considered adequate, where a response is called for.

A number of EPA's comments were directed at the draft Appendix VI. Most of the specific comments are no longer of interest, because the revision of Appendix VI has substituted new material for that which was the subject of the comment. However, the revised Appendix VI has two of the principal deficiencies addressed in our comments of November 1974 on draft WASH-1400. A substantial deficiency is the use of health effects models which tend toward underestimation of the number of health effects. The other deficiency is the inadequacy of the description of the process used for calculating consequences.

F. References

1. HANS, J. M. Jr., and T. C. SELL. Evacuation risks - An evaluation. U.S. Environmental Protection Agency. NERC-LV EPA-520/6-74-002. (1974)

2. LILLIEFORS, H. W. On the Kolmogorov-Smirnov test for normality with mean and variance unknown. JASA 62: 318. pp. 399-402. (June 1967).

3. BROWNLEE, K. A. Statistical theory and methodology in science and engineering. Second Edition, John Wiley and Sons Inc., New York. (1960)

4. DRAPER, N. R. and H. SMITH. Applied regression analysis. John Wiley and Sons Inc., New York. (1966)

5. BROWNLEE. p342.

6. DRAPER and SMITH. pp. 21-24.

SECTION 4

REPORT BY INTERMOUNTAIN TECHNOLOGIES INC.

A REVIEW OF THE FINAL REPORT
REACTOR SAFETY STUDY
WASH-1400

The contract report reproduced as Section 4 of this report was prepared as an account of work sponsored by the Environmental Protection Agency. The contract report is being published so that it will be available as a resource to the scientific community and the general public. It does not necessarily represent the views or policies of the Environmental Protection Agency.

A REVIEW OF THE FINAL REPORT
REACTOR SAFETY STUDY (WASH-1400)

APRIL 1976

BY

P. R. DAVIS

INTERMOUNTAIN TECHNOLOGIES, INC.
505 Lomax P.O. Box 1604
Idaho Falls Idaho 83401

Contract No. 68-01-2244

Project Officer

Dr. Jerry Swift

Office of Radiation Programs

Prepared for
Office of Radiation Programs
U. S. Environmental Protection Agency
Washington, D. C. 20460

LEGAL NOTICE

This report was prepared by Intermountain Technologies, Inc. (ITI) as an account of work sponsored by the Environmental Protection Agency (EPA). Neither ITI, nor any person acting on behalf of ITI;

a. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe privately owned rights; or

b. Assumes any liabilities with respect to the use of, or for damage resulting from the use of, any information, apparatus, method or process disclosed in this report.

TABLE OF CONTENTS

		Page
LEGAL NOTICE		4-2
TABLE OF CONTENTS		4-3
LIST OF TABLES		4-4
ABSTRACT		4-5
SECTIONS:		
I.	CONCLUSIONS	4-7
II.	RECOMMENDATIONS	4-10
III.	INTRODUCTION	4-13
IV.	GENERAL RESULTS	4-14
V.	ANALYSIS	4-28
VI.	ADDITIONAL COMMENTS	4-76
VII.	REFERENCES	4-81
VIII.	GLOSSARY	4-82

LIST OF TABLES

Table		Page
I.	Summary Description of Apparent Technical Deficiencies Found in WASH-1400	4-17
II.	Summary Description of Apparent Deficiencies from General Observations	4-22
III.	Summary Status of Apparent Deficiencies in WASH-1400 (final)	4-24
IV.	Summary of Risk Significance of Apparent Deficiencies in WASH-1400 (final)	4-25
V.	WASH-1400 (final) Unresolved Areas with Potential Risk Changes	4-26
VI.	Application of Surry Risk Analysis to Trojan	4-69

ABSTRACT

This report is an addendum to our report entitled, "A Review of the Draft Report - Reactor Safety Study (WASH-1400)" which was included in a publication of the U.S. Environmental Protection Agency entitled, "Reactor Safety Study (WASH-1400): A Review of the Draft Report" (EPA-520/3-75-012) issued in August 1975. The purpose of this report is to present the results of a review of the final version of WASH-1400 dated October 1975. The Review consisted of examining the same areas of the final version of WASH-1400 which were considered in depth during the review of the draft (reported on in EPA 520/3-75-012) and to modify, if appropriate, the conclusions reached from the review of the draft version.

The clarification and revised analyses contained in WASH-1400 (final) resulted in some significant improvements over the draft document. Improvements have been made in many of the areas found to be deficient by the EPA review of the draft. In general, however, the ITI conclusions reached from the review of the draft are found, in the present review, to remain applicable to the final version of WASH-1400.

This report was submitted in fulfillment of Contract Number 68-01-2244 (Modification No. 4) by Intermountain Technologies, Inc. under sponsorship of the Environmental Protection Agency. Work was completed as of April 1976.

INTENTIONALLY LEFT BLANK

I. CONCLUSIONS

The purpose of the effort described in this report was to review the final version of WASH-1400(1) to determine whether the conclusions resulting from the ITI review of the draft are still valid. The conclusions resulting from the draft review are contained in Reference (2).

The conclusions resulting from the review of the final version of WASH-1400 are as follows:

A. The final version of WASH-1400(1) has been improved compared to the draft version(3).

B. While some deficiencies in WASH-1400 Draft have been either clarified, improved, or eliminated, the conclusions from the review of the draft, with generally minor modifications, are judged to still apply to the final version. The conclusions are as follows:

   (1) Although errors, omissions, inconsistencies, and questionable assumptions still exist in some areas of WASH-1400 (final), the majority of these deficiencies do not have a significant effect on the overall risk assessments.

   (2) The summary presentations in WASH-1400 (final) for comparing the risks of nuclear power with other man-caused risks are sometimes misleading and incomplete. Factors such as not illustrating calculational uncertainties in nuclear power risks, making comparisons of calculated nuclear risks

with actual risks from other sources without emphasizing the distinction sufficiently, and particularly obscuring latent deaths from nuclear power, all tend to undermine the strength of the WASH-1400 (final) conclusions, both expressed and implied.

(3) The WASH-1400 (final) risk assessment from transient without scram accidents for boiling water reactors appears to be the most significant analysis problem found in the report. In this case, a preliminary sensitivity study indicates that re-evaluation of the consequences of this accident may increase the WASH-1400 calculated risks from BWRs.

(4) Several areas were found which appear to be improperly or incompletely considered but for which insufficient information is available to determine quantitatively their risk impact. These areas include

- human reliability
- PWR small break calculational techniques
- common mode failure quantification
- some aspects of design adequacy.

(5) The validity of applying the results of the risk assessment using the Surry reactor, chosen to represent all PWRs in WASH-1400 (final), to the 60 to 70 PWRs expected to be in operation by 1980 needs additional consideration in WASH-1400 (final). In several areas, design differences between the Surry plant and a plant more representative of the 1980 plant population indicate that the Surry results may not apply. Surry represents a PWR design similar to only about 20 percent of the anticipated 1980 PWR population.

(6) The basis for selecting the PWR containment failure pressure was found to be deficient, and the failure pressure selected appears to be too high.

(7) The assessment of ECCS functionability appears to be incomplete. Conclusions are stated which may be misleading.

II. RECOMMENDATIONS

It is recommended that three separate activities be undertaken by NRC, as follows:

A. The 13 apparent deficiencies which have been found to still exist in WASH-1400 (final) and which have the potential for changing the risks should be resolved. These areas are discussed in Section IV and are tabulated in Table V. The assessment and presentation of risks from latent fatalities should also be resolved (see Section V, item 17c, and Section II, item 2).

B. A revised study of the risks of nuclear power should be undertaken no later than 1981. This revised study should include the following:

   (1) A resolution of the 21 deficiencies described in this report which are not covered by recommendation A above. Although these deficiencies do not appear to have a significant effect on the risk assessments, they should be repaired for the following reasons: (a) The existence of errors, omissions, inconsistencies and questionable assumptions in the report tends to undermine the confidence gained by the reader in the results, especially since in many cases the significance of such deficiencies is not obvious. (b) As changes are made in the report, the effect of some of the minor problems could be amplified. Changes in reactor design, as well as operating and maintenance characteristics, could shift the emphasis and accentuate the significance of deficiencies which presently appear to be minor.

(2) Comparisons between nuclear and other man-made risks should be revised to clearly and consistently indicate:

   (a) that the nuclear risks are calculated while other risks are derived from actuarial data,

   (b) the substantial uncertainty associated with the nuclear risk calculations,

   (c) the latent death risk from nuclear power plants.

(3) The next version of the Study should cover PWR designs other than that represented by the Surry plant selected for analysis in WASH-1400. Of the 60 to 70 PWRs expected to be operating by 1980 (stated to be covered by the WASH-1400 results), only about 20 percent are of the Surry design. Some of the plants differ in design considerably from the Surry plant, and further assurance is needed that the Surry results apply to these plants as assumed by WASH-1400. An analysis of risks from offshore plants should also be considered in the next version if this technology becomes a reality.

C. The Study should be continuously maintained. It is likely that the power plants covered by the Study will undergo design, operational, and maintenance and testing changes, some of which may be required by regulatory agencies. These changes should be factored into the Study in a timely manner to determine the effect of such changes on the risk evaluation. As the number of operating reactor-hours increases, the component failure rate and accident frequencies should be monitored and periodically factored into the Study. This would improve the statistical basis in the Study and could alter some of the results. Continuous maintenance of the Study would not only sharpen the focus of the quantitative risk assessments, but would also have the potential of promptly identifying problem areas as well as improving the methods used in the Study.

III. INTRODUCTION

In August 1974, the United States Atomic Energy Commission (AEC) issued a draft document, entitled "Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants" (WASH-1400). The document concluded that risks to the general public from power reactor accidents are substantially less than from other man-made risks and most natural disasters.

In December 1975, the Nuclear Regulatory Commission issued a final version of WASH-1400(1). This version was modified from the draft version, based, in part, on comments received from various reviewers. The final version also concludes that risks to the general public from power reactor accidents are substantially less than from other man-made risks and most natural disasters. A new appendix (Appendix XI - Responses to Comments on WASH-1400 Draft) has been added to the final version. This appendix lists and discusses some of the comments received from the major reviews of WASH-1400 Draft.

The United States Environmental Protection Agency (EPA) reviewed WASH-1400 Draft and published the results of their review in August 1975. To provide assistance for the review, the EPA contracted with Intermountain Technologies, Inc. (ITI). The results of the ITI review are contained in Reference 2. Following the issuance of the final version of WASH-1400, the EPA extended the contract with ITI to provide for (1) an examination of the same aspects of WASH-1400 (final) and (2) revisions, where appropriate, of the findings resulting from ITI's review of WASH-1400 Draft. The purpose of this report is to describe the results of the ITI effort.

The ITI review of WASH-1400 (final) consisted mainly of three phases. A search of Appendix XI was made initially to determine if the deficiencies found in each of the areas analyzed during review of WASH-1400 Draft were considered. If the deficiencies were considered and responded to, an assessment was made of the response. The second phase consisted of determining if modifications had been made to the area analyzed and found to be deficient during review of WASH-1400 Draft. If modifications were made, an assessment was completed to determine if the deficiencies still existed. The third and final phase consisted of evaluating whether the overall conclusions as stated in the review of WASH-1400 Draft were still applicable and, if not, to make appropriate modifications.

IV. GENERAL RESULTS

The general results of the review of the areas in WASH-1400 (final) which correspond to areas found deficient in the draft review are presented in Tables I and II. Table I presents the results of the review of the engineered safety systems, accident sequences, and component failure assessments which are contained in WASH-1400 (final). The first column indicates the general area considered, the second column describes the deficiency found in the review of WASH-1400 Draft, and the next four columns summarize whether the deficiency was considered in WASH-1400 (final) and whether the deficiency, if considered, was adequately resolved. The last column indicates an assessment of the potential effect on the calculated risk, if any, associated with the deficiency if it still exists in WASH-1400 (final).

Table II summarizes the results of a review of the deficiencies identified in the General Observations section of the review of WASH-1400 Draft(2). This table has the same format as Table I.

Table III is a composite showing how many of the 45 deficiencies found in WASH-1400 Draft (listed in Tables I and II) were considered and revised in WASH-1400 (final).

Table IV illustrates the number of deficiencies remaining in WASH-1400 (final) which have the potential for altering the risk. The table also shows whether each deficiency would tend to increase or decrease the risk and, where determined, the significance of the change (the potential change associated with five deficiencies was not determined).

Table V lists the thirteen deficient areas remaining in WASH-1400 which appear to have either a significant (one area) or unknown potential for changing the calculated risks.

In summary, the tables indicate that of the 45 deficiencies found in the review of WASH-1400 Draft (Tables I and II), 34 still remain unresolved in WASH-1400 (final) as shown in Table III. Of these, 29 have the potential for changing the calculated risk. Sixteen of the 29 were judged to have an insignificant effect on the risk, leaving 13 with either a significant (one item) or unknown potential for changing the calculated risks (Table V).

It should be noted that the deficiencies represent areas where, based on an independent judgment, a problem exists. It is possible that in some cases the deficiency results from a misunderstanding of the information presented in WASH-1400.

TABLE I - Summary Description of Apparent Technical Deficiencies Found In WASH-1400

Area	Deficiency Identified in Draft Review (1)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
1. BWR Reactor Protection System	a. Conservative assumption-three adjacent rod failures cause scram failure	Yes	Appears Inadequate	No	-	decreased (U)
	b. Single control rod failure rate too low	Yes	Adequate	No	-	none
	c. Common mode failure consideration inadequate	Yes	Appears inadequate	No	-	increased (S)
	d. Excessive credit taken for manual poison injection	Yes	Adequate	Yes	adequate	none
2. BWR Transient Accident	a. Inadequate consideration of the frequency and severity of anticipated transients	Yes	Adequate	No	-	none
3. BWR Electric Power System Failure	a. Loss of two diesels rather than four for LPCI failure	No	-	No	-	increased (I)
4. PWR Electric Power System Failure	a. Insufficient consideration for availability of power at LOCA	No	-	No	-	increased (I)
	b. Time and environmental effects on failure rate not considered	Yes	Partially adequate	No	-	increased (U)
	c. Probability too low for operator opening wrong breakers	Indirectly	Inadequate (for this specific area)	No	-	increased (I)
	d. Evaluation of d.c. power unavailability not adequate	No	-	Yes	adequate	none

(1) see Reference 2 for a complete description of the deficiency

U - Amount of potential risk change undetermined

I - Amount of potential risk change judged to be insignificant

S - Amount of potential risk change judged to be significant (more than a factor of 10)

TABLE I (continued)

Area	Deficiency Identified in Draft Review (1)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
	e. Insufficient error consideration of operator opening wrong break	No	-	No	-	increased (I)
	f. Maintenance errors resulting in bus unavailability not considered	Indirectly	Probably adequate	No	-	none
	g. Possible incomplete consideration of diesel generator unavailability	No	-	No	-	increased (I)
	h. Earthquake relay failure trips in diesel, and load breaker location not considered	Indirectly	Partially adequate	No	-	increased (U)
5. PWR High Pressure Injection System	a. Operator reliability to open water valves to lube oil coolers too high	Indirectly	Inadequate (for this specific area)	No	-	increased (I)
	b. LPIS check valve failure not adequately considered	No	-	No	-	increased (I)
	c. Additional double failures not included: failure of both valves in 1) volume control tank drain, 2) normal charging line, 3) boric acid recirculation system.	No	-	No	-	increased (I)

(1) See Reference 2 for a complete description of the deficiency

U - Amount of potential risk change undetermined
I - Amount of potential risk change judged to be insignificant
S - Amount of potential risk change judged to be significant (more than a factor of 10)

TABLE 1 (continued)

Area		Deficiency Identified in Draft Review (1)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
6. PWR Small Break Loss of Coolant Accident Analysis	a.	Assumption of adequate core cooling for small breaks not justified	Yes	Inadequate	No	--	increased (U)
7. PWR Loss of Power Transient Accident Sequence	a.	Containment loading from steam when accumulator water contacts core melt	Partially	Partially adequate	No	--	increased (I)
8. Component Failure Modes and Rates	a.	Assessed failure probability not consistent with data in several areas	Yes	Partially adequate	Partially	Improved	unknown (I)
9. Human Reliability Analyses	a.	Inadequate and inconsistent derivation of specific human reliability assessments	Yes	Inadequate (more work said to be useful)	No	--	unknown
10. Common Mode Failures	a.	Insufficient description of how common mode failures were quantified and applied	Yes	Partially adequate	Yes	Improved	unknown
11. Design Adequacy	a.	Insufficient description of the extent which design adequacies were assessed and applied	Yes	Inadequate	No	--	unknown

(1) See Reference 2 for a complete description of the deficiency

U - Amount of potential risk change undetermined
I - Amount of potential risk change judged to be insignificant
S - Amount of potential risk change judged to be significant (more than a factor of 10)

TABLE I (continued)

Area	Deficiency Identified in Draft Review (1)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
12. PWR Low Pressure Injection System Failure	a. Incorrect value assigned to probability of the operator closing second wrong valve	No	-	No	-	increase (I)
13. PWR Low Pressure Recirculation System	a. Operator error-incorrect probability for failure to open valves	No	-	No	-	increase (I)
	b. Operator error-no consideration of single failure valve closure.	No	-	No	-	increase (I)
	c. Valve faults incorrectly placed and counted twice	No	-	No	-	decrease (I)
	d. Operator switching to hot leg recirculation after hot leg break not considered	No	-	No	-	increase (I)
14. Core Meltdown Analysis	a. Time to core melt excessive	Yes	Adequate	No	-	none
15. Containment Failure Pressure	a. Surry containment failure pressure not sufficiently justified and appears high	Yes	Inadequate	No	-	increase (U)
16. Containment Pressure Response	a. Containment failure time should be reduced for CSIS and CSRS failure	No	-	No	-	increase (U)

(1) See Reference 2 for a complete description of the deficiency

U - Amount of potential risk change undetermined
I - Amount of potential risk change judged to be insignificant
S - Amount of potential risk change judged to be significant (more than a factor of 10)

TABLE I (continued)

Area	Deficiency Identified in Draft Review (1)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
	b. Containment failure time should be increased for loss of electrical power	No	-	No	-	decrease (U)

(1) See Reference 2 for a complete description of the deficiency

(U) - Amount of potential risk change undetermined

TABLE II - Summary Description of Apparent Deficiencies from General Observations(1)

Area	Deficiency Identified in Draft Review (2)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
17.(3) Comparative Risk Curve	a. Calculated vs actual risks not distinguished in comparative curves	No(4)	-	No	-	N.A.
	b. Calculational uncertainties not sufficiently emphasized	Yes	Adequate	Yes	Adequate	N.A.
	c. Latent deaths not sufficiently emphasized	Yes	Inadequate	Yes	Inadequate	N.A.
	d. Transition from solid to dashed lines in man-caused risks does not correspond to data	No	-	No	-	N.A.
18. Nuclear Plant Characteristics	a. Distribution of plant types not considered	No	-	Yes	Adequate	None
	b. Risks computed based on incorrect power level	No	-	No	-	decrease (I)
	c. Application of Surry risk analysis to other PWRs not justified	Yes	Probably adequate	No	-	unknown (possibly decrease - see Analysis section)
19. Realistic vs Conservative Assumptions	a. Indicated realism not consistently used	No	-	No	-	decrease (U)

---

(1) See Reference 2 for discussion of General Observations
(2) See Reference 2
(3) Areas continued from Table I
(4) Comment is listed but not answered

I - Insignificant
U - Undetermined
N.A. - Not applicable

TABLE [illegible] (continued)(1)

Area	Deficiency Identified in Draft Review (2)	Deficiency Considered In Appendix XI	Assessment of Appendix XI Response	Area Revised In WASH-1400 Final	Assessment of Revision	Potential Risk Change
20. Comparison of Risks Between Nuclear and Other means of Electrical Power Generation	a. Comparison between nuclear and non-nuclear electrical power generation risks is required	No	-	No	-	N.A.
	b. Inadequate emphasis that risks are from in-plant accidents only	Yes	Inadequate	No	-	N.A.
21. General Inconsistencies	a. Study contains inconsistencies in approach and level of detail considered	No	-	Yes	Improved	N.A.
22. Conclusions	a. Continuous up-grading of study required	Yes	Adequate	N.A.	-	N.A.
	b. Expansion to incorporate different reactor concepts required	Yes	Adequate	N.A.	-	N.A.

---

(1) See Reference 2 for discussion of General Observations

(2) See Reference 2

TABLE III - Summary of Apparent Deficiencies in WASH-1400 (final)(1)

Total Number of Deficiencies in WASH-1400 draft	Considered in WASH-1400 (final) (Appendix XI)			Revisions made in WASH-1400 (final)				Total Number of Deficiencies Remaining in WASH-1400 (final)
	Number Considered	Assessment		Number Revised	Assessment		Improved	
		Adequate(2)	Inadequate		Adequate	Inadequate		
43	23	14	9	8	4	1	3	34

(1) does not include problems discussed in Section VI

(2) includes those judged to be partially adequate.

TABLE IV - Summary of Risk Significance of Apparent Deficiencies in WASH-1400 (final)

Total Number of Deficiencies remaining in WASH-1400 (final) with Potential for change in Risk	Potential Change in Risk(1)						
	Increase			Decrease			Unknown
	Significant	Insignificant	Undetermined	Significant	Insignificant	Undetermined	
29	1	13	5	0	2	3	5 (1 insignificant)

---

(1) Significant is defined as having the potential for changing the risks by more than a factor of 10.

TABLE V - WASH-1400 (final) Unresolved Areas with Potential Risk Change

Deficient Area	Section V Discussion	Potential Risk Change
1. BWR Reactor Protection System: Conservative Assumption - three adjacent rod failures cause scram failure	Page 4-29	decrease - extent unknown
2. BWR Reactor Protection System: Common mode failure consideration inadequate	Page 4-33	increase - significant
3. PWR Electric Power System Failure: Time and environment effects on failure rate not considered	Page 4-39	increase - extent unknown
4. PWR Electric Power System Failure: Common mode failures due to earthquakes, relay failure, and breaker location not considered	Page 4-44	increase - extent unknown
5. PWR Small Break Loss of Coolant Accident Analysis: Assumption of adequate core cooling for small breaks not justified	Page 4-47	increase - extent unknown
6. Human Reliability Analysis: Inadequate and inconsistent derivation of specific human reliability assessments	Page 4-52	unknown
7. Common Mode Failures: Insufficient description of how common mode failures were quantified and applied	Page 4-53	unknown
8. Design Adequacy: Insufficient description of the extent which design adequacies were assessed and applied	Page 4-54	unknown
9. Containment Failure Pressure: Surry containment failure pressure not sufficiently justified and appears too high	Page 4-58	increase - extent unknown

TABLE V (Continued)

Deficient Area	Section V Discussion	Potential Risk Change
10. Containment Pressure Response: Containment failure time should be reduced for CSIS and CSRS failure	Page 4-59	increase - extent unknown
11. Containment Pressure Response: Containment failure time should be increased for loss of electrical power	Page 4-60	decrease - extent unknown
12. Nuclear Plant Characteristics: Application of Surry risk analysis to other PWRs not justified	Page 4-67	unknown
13. Realistic vs Conservative Assumptions: Indicated realism not consistently used	Page 4-71	decrease - extent unknown

V. ANALYSIS

This section presents the analysis of each of the 45 deficiencies found during the review of WASH-1400 Draft(2). The analysis consists of determining the extent to which the deficiency still exists in WASH-1400 (final)(1). The analysis includes two distinct evaluations for each deficiency. First, a determination was made if the deficiency was considered in Appendix XI to WASH-1400 (final). Appendix XI lists and responds to selected comments which were received by the Nuclear Regulatory Commission (NRC) subsequent to the publication of WASH-1400 Draft in August 1974. If the deficiency was considered and responded to in Appendix XI, an assessment is given of the adequacy of the response. Second, the area in WASH-1400 Draft which contained the deficiency was found in WASH-1400 (final) and reviewed to determine if an adequate revision was made. A discussion is presented of both the response and revision, if they exist. The deficiencies are separated into two groups. The first group consists of deficiencies found during the review of the 16 technical areas selected for assessment in WASH-1400 Draft. The detailed review of these areas is contained in Section V, Part 3 of Reference 2. The second group consists of deficiencies found in the general assumptions and presentation of results. These deficiencies are contained in Section VI (General Observations), Part 3 of Reference 2.

The deficiencies, and an analysis of them based on information contained in WASH-1400 (final), are as follows:

1. BWR Reactor Protection System Failure

A total of four deficiencies were found during the review of the BWR reactor protection system as described in WASH-1400 Draft. These deficiencies, and an evaluation of them based on WASH-1400 (final), are as follows:

a. *Conservative assumptions: three adjacent rod failures cause scram failure* - WASH-1400 Draft assumed that the failure of any three adjacent control rods to insert in a BWR core resulted in a scram failure. This assumption was judged to be excessively conservative and not consistent with the WASH-1400 charter of performing a realistic analysis.

Appendix XI Response - The deficiency described above (and in more detail in reference 2) was considered in Appendix XI of WASH-1400 (final) on pages XI 5-2 and 5-3. The response indicated basically that "the major contributors to scram failure are common mode failures of scram rods and common mode failures due to test and maintenance. These common mode contributions would give essentially the same probability of failure for not only three rods but also for four or more rods. Within the data accuracies, then, the total scram probability of $1.3\text{x}10^{-5}$ applies to either three or four (or more) rod failures."

To determine the adequacy of the above response, Section 6.2.4.1 ("Reactor Protection Control Rod System"), page II-359 (Appendix II) was reviewed. The contributors to RPS failure are (page II-358):

$Q_{\text{doubles}} = 3.2\text{x}10^{-8}$

$Q_{\text{triples}} = 5.8\text{x}10^{-6}$

$Q_{\text{test + main}} = 2.6\text{x}10^{-7}$

$Q_{\text{common mode}} = \underline{1.9\text{x}10^{-6}}$

TOTAL $8.0\text{x}10^{-6}$

As can be seen, the $Q_{triples}$ contribution represents over 70% of the total. The $Q_{test + main}$ (test and maintenance contribution) is insignificant (∿3%) and $Q_{common\ mode}$ contributes less than 25%, and has to do with miscalibration of switches that produce a trip signal. There is a common mode contribution included in the $Q_{triples}$ value which apparently is the contribution referred to in the Appendix XI response. To determine how this contribution is affected by a change in the number of rods that are required to fail to prevent scram, an analysis was conducted using the WASH-1400 method of incorporating common mode failures for this case as described on page II-362. Assuming, for example, that it takes four adjacent rod failures to prevent scram rather than three, the assumption of complete independence yields (page II-362).

$$(1x10^{-4})^4 = 1x10^{-16}$$

which would be the failure rate for any four rods assuming no common mode contribution. Using the WASH-1400 (page II-362) value for the common mode contribution ($1x10^{-6}$) and combining the two values in a log-normal median fashion as was done in WASH-1400 yields,

$$P_4 = \sqrt{(1x10^{-16})\ (1x10^{-6})} = 1x10^{-11},$$

which is a factor of 100 below the WASH-1400 assessment for P_3 given on page II-362, indicating that the common mode contribution is not a major contributor to control rods failing to insert, contrary to the contention in Appendix XI. This reduction will significantly reduce both cases (a) and (b) which were combined to produce the Q_{triple} contribution of $5.8x10^{-6}$.

Page II-359 of Appendix II, WASH-1400 (final), describes the assumption of three adjacent control rod failures as leading to "an extremely conservative analysis" of the reactor protection systems. This statement seems to conflict with the assessment in Appendix XI described previously. Also, testimony by representatives from General Electric at a recent ACRS meeting on ATWS(9) tends to confirm the extreme conservatism of the assumption.

Analysis Change - No change was found in the WASH-1400 final analysis compared to WASH-1400 draft relative to the assumption of three adjacent control rod failures causing scram failure (Appendix II, page II-359 et seq.).

Conclusion - The WASH-1400 (final) response to the deficiency identified from the review of WASH-1400 Draft relative to the assumption of three adjacent control rod failures is assessed to be inadequate based on the foregoing analysis. However, it does not appear that this assumption results in an overly significant influence on the calculated BWR risks since, at most, it could result in a factor of 4 reduction in the RPS failure probability since other contributions become dominant. However, further analysis is required to definitely quantify the effect. It should be noted that the WASH-1400 method of accounting for common mode failures in the manner described on page II-362 has been questioned and is discussed in area I-c, following. These two areas are quite dependent and changes in one can affect the results in the other.

Miscellaneous Comments - Discussions with the General Electric Co.(4) tended to confirm the conservatism of assuming any three adjacent control rod failures cause scram failure. In fact, based on G.E.'s assessments, the loss of either subsystem A or B control rods (each subsystem controls 1/2 of the control rods) will not result in failure to scram for some anticipated transients. Thus, the common mode failure contribution for each of these systems (described on page II-363) may not be properly assessed.

b. *Single control rod failure rate too low* - WASH-1400 Draft assessed the probability of failure for a single control rod to be 1×10^{-4}. This was assessed to be not substantiated by data included in WASH-1400, and possibly too low based on an independent assessment by others. Also, WASH-1400 uses only two failures to compute the control rod failure probability while Table III-7 in WASH-1400 Draft indicates six failures occurred during the time period used.

Appendix XI Response - It is stated on page VI 5-3 that additional control rod failure data for 1973 were analyzed which confirmed the WASH-1400 value. Only two of six failures listed in WASH-1400 Draft resulted in failure to insert on demand.

Analysis Change - No change to the analysis of single control rod failure probability was found in WASH-1400 (final) (page II-362).

Conclusions - It is concluded that the WASH-1400 value of 1×10^{-4} for single control rod failure probability is probably valid. Discussions with G.E.(4) tended to support the value.

Miscellaneous Comments - References to Tables III 4-5 and III 5-3 on page XI 5-3 of WASH-1400 (final) are all incorrect.

c. *Common mode failure consideration inadequate* - The derivation of $1x10^{-6}$ for the "tight coupling" common mode contribution and the subsequent log-normal combination of this value with the "complete independence" ($1x10^{-12}$) value to obtain the probability of three control rod failures was considered faulty during the WASH-1400 Draft review. The $1x10^{-6}$ value was derived by multiplying the basic single control rod failure rate ($1x10^{-4}$) by 0.1 which, according to WASH-1400 Draft, is the approximate common mode failure frequency. A second factor of 0.1 was used to account for the fact that only 10% of the common mode failures resulted in complete failure to insert; the other "failures" resulted in partial degradation. During the WASH-1400 Draft review, it was concluded that (1) there was insufficient justification provided to support the assumption that 10% of the control rod failures were common mode, and (2) based on the derivation of the common mode contribution ($1x10^{-6}$) in WASH-1400 Draft, it appeared that $1x10^{-6}$ should be used as the probability of three adjacent rods failing rather than a value ($1x10^{-9}$) obtained by combining the common mode contribution with the completely independent contribution. Using a value of $1x10^{-6}$ produced a factor of 30 increase in the BWR risks.

Appendix XI Response - WASH-1400 (final) (page XI 5-3) did consider this apparent deficiency. The response states, "The 10^{-6} value was obtained from the analyses described in Appendix III in which approximately 10% of all failures could be considered as approximating common mode behavior. Since all types of components were considered in obtaining this 10% value and since many of the common modes did not cause failure but only minor degradations, this 10^{-6} value was treated as very conservative and, hence, as being an upper bound."

Analysis Change - No change in the value of the probability of three adjacent control rod failures was found in WASH-1400 (final) (Section 6.2.5.1, page II-362).

Conclusion - The Appendix XI response is judged to be inadequate, and the assessment of the deficiency from the WASH-1400 Draft review is still considered valid. The response seems to indicate that the 10^{-6} value does not include a consideration that many common mode "failures" result in only "minor degradations," and thus the value represents an upper bound. However, the "minor degradation" contribution is said to be accounted for in WASH-1400 by the additional factor of 0.1 in arriving at the 10^{-6} value so that the upper bound argument is not valid. There is no additional justification in the Appendix XI response for the validity of either the 10% value used for the common mode contribution or the additional 10% value used to account for the minor degradation contribution. However, Table III 3-6 (pages 37 and 38) contained in Appendix III, WASH-1400 (final), does list common mode effects and causes, and does illustrate that a 10% contribution from common mode failures may be reasonable.

Miscellaneous Comment - There appear to be major differences between the WASH-1400 results of the BWR RPS failure probability and General Electric's assessment. G.E., in recent testimony(9), indicated that the RPS failure probability, considering random failures only, was

2×10^{-9} per demand. This compares to the WASH-1400 value of 3×10^{-7} obtained by taking out the common mode failure contributions from the failure mechanisms listed on page II-358 (Section 6.2.3).

d. *Excessive credit taken for manual poison injection* - It was concluded from the review of WASH-1400 Draft that (1) the probability of operator failure to initiate the liquid poison injection system during an anticipated transient was too low (3×10^{-2}), and (2) for at least some severe anticipated transients, the liquid poison injection system was too slow to have any effect on the transient.

Appendix XI Response - According to Appendix XI (page XI 5-1), the WASH-1400 Draft value of 3×10^{-2} for the probability of operator failure to activate the liquid poison injection system was too low. An increased value of 10^{-1} has been assigned in WASH-1400 (final). Relative to the effectiveness of the liquid poison injection system, Appendix XI (page 5-8) argues that all anticipated transients are slow enough to be adequately controlled by activation of the liquid poison injection system assuming that fuel melting must be prevented. Further, exceeding primary system pressure and fuel temperature limits, which are very conservative, does not imply that an accident has occurred or that a radiological consequence to the public will result.

Analysis Change - The value for the probability that the reactor operator unsuccessfully initiates the liquid poison injection system has been increased to 1×10^{-1} in WASH-1400 (final). The assumption that the liquid poison injection system can successfully terminate all anticipated transients has been retained in WASH-1400 (final).

Conclusion - The WASH-1400 (final) assessment of the BWR liquid poison injection system now appears adequate relative to the two areas described in the preceding discussion. Discussions with G.E.(4) revealed that even for the most severe transients (ie, main steam line isolation valve closure), the operator has sufficient time (hours) to successfully initiate the liquid poison injection system provided that recirculation pump trip occurs (failure of recirculation pump trip was assessed to be negligible in WASH-1400).

Miscellaneous Comment - It should be noted that, as a result of Nuclear Regulatory Requirements(5), the need and possible mechanism for improving the BWR reactor protection system has been reviewed by General Electric Co. A report(6) has been submitted to NRC which contains a proposal to change the BWR Reactor Protection System by, among other alterations, making the Liquid Poison Injection System an automatically controlled system thereby reducing operator error. This proposal is currently under review by NRC and, if accepted, will render the WASH-1400 (final) assessment of BWR RPS failure invalid for those plants which are modified to meet the proposal.

2. BWR Anticipated Transients

One deficiency was found in this area during the review of WASH-1400 Draft.

a. *Inadequate consideration of the frequency and severity of BWR anticipated transients* - It was concluded from the review of WASH-1400 Draft that the assumed frequency of BWR Anticipated Transients

(10/yr) was too high and that the actual frequency of those anticipated transients which require core power shutdown should be 3/yr.

Appendix XI Response - On pages XI 5-8 and 5-9, WASH-1400 (final) states that "Reactor experience clearly indicates that a frequency of about 10 transient events per reactor-year must be considered."

Analysis Change - No change in the assessed frequency of BWR anticipated transients was made in WASH-1400 (final) (Appendix V, page V-36).

Conclusion - Based on a review of Reference 6 as well as discussions with G.E.(4), it appears that the WASH-1400 assessment of BWR anticipated transient frequency is correct.

Miscellaneous Comments - Reference 6 describes nine anticipated transients which are "...derived for ATWS consideration on the basis of operational experience and have the potential of a frequency of occurrence of at least once in four years of reactor operation at power conditions such that a significant transient results and scram is called upon to shut down the reactor." Table I 4-12 (page I 91/92, "BWR Transients") of WASH-1400 (final) lists 14 occurrences which are called "Likely Initiating Events" (also "likely transient events" on page I-64). Eight of the nine transient events contained in the Reference 6 list are included in the WASH-1400 (final) list. (Inadvertent opening of the safety relief valves is not included.) It is not clear why these lists are inconsistent.

3. BWR Electric Power System Failure

One deficiency was found in this area during the review of WASH-1400 Draft.

a. *Loss of two diesels rather than four for LPCI failure* - It was determined during the review of WASH-1400 Draft that an incorrect assumption was made regarding the number of diesels required to permit continued operation of the Low Pressure Coolant Injection System. WASH-1400 Draft assumed that the LPCI system would have insufficient capacity only if all four diesels were lost coincident with loss of offsite power. A review of information contained in WASH-1400 Draft (Appendix II, Vol. 3) as well as the Peach Bottom SAR(7) (Table 8.5.2b) led to the determination that loss of two diesels would result in loss of LPCI capacity.

Appendix XI Response - None.

Analysis Change - None (Section 6.4.2 of WASH-1400 (final) unchanged, in this regard, from corresponding section in Draft).

Conclusion - This discrepancy apparently remains in WASH-1400 (final).

4. PWR Electric Power System Failure

Eight discrepancies were found in this area during review of WASH-1400 Draft as follows:

a. *Insufficient consideration given to availability of power at inception of LOCA* - WASH-1400 Draft did not consider (1) that the Technical Specifications, which require reactor shutdown if an emergency bus becomes unavailable, could be violated, and (2) that the detectors, indicators, or annunciators which tell the operator that he is without a bus may fail.

Appendix XI Response - None.

Analysis Change - None (PWR Electric Power System analysis as presented on page II-8.6 is unchanged from WASH-1400 Draft).

Conclusion - The apparent deficiency still exists in WASH-1400 (final).

b. *Time and environmental effects on failure rate not considered* - WASH-1400 Draft did not appear to account for the fact that grounds and faults on the PWR electric power systems may be affected by aging and by extended exposure to the relatively harsh LOCA environment.

Appendix XI Response - A general response to the problem of aging effects on component failures is given on page XI 14-3. The point is made that the study results apply only to the 100 plants operating in the next five years, and suggests that the study be repeated in about five years. Also, it is stated that "Aging is a separate question that perhaps could be analyzed when and if data are available and, more importantly, if the need to do so clearly existed." An Appendix XI response to another comment (comment 7, page XI 2-4) also seems appropriate to this issue, although it was not used as such. On page XI 2-4, it is stated that some of the failure data examined was derived from actual field operation. Thus, it is reasonable to assume that aging effects were included in at least part of the data base as casually related failures.

Regarding LOCA environmental effects on the PWR electric power system components, a general response is given in Appendix XI, page 2-5 to the effect that environmental effects were considered in Appendix X (Design Adequacy). A review of Appendix X reveals that "On-Site Electric Power System" (item A6.3.6) is listed as an item in

Table X 2-2 entitled "PWR Component Review - Environmental Qualification Summary." However, for reasons not explained, none of the columns which describe the extent of the review or the results are checked. A further investigation of Appendix X revealed that on page X-58 a narration is provided relative to item A6.3.6 which is renamed "Electric Power Distribution Systems." This system is said to consist of "transformers, switchgear and motor control centers, emergency buses, containment penetrations, and associated electric power and control cables and their supporting cable trays." The section next describes separately "Electrical Cables and Terminations" (A6.3.7.1), "Electrical Containment Penetrations and Connectors" (A6.3.7.2), "Cable Trays" (A5.3.7.3), and "A-C and D-C Switchgear" (A6.3.7.4). None of the other components said to be included in the PWR Electrical Power Distribution Systems is considered further. Appendix X concludes that, for the components described separately (Sections A6.3.7.1 through A6.3.7.4), the electrical cables and terminations with "reasonable assurance" will perform adequately during and following design basis events at the plant. For "Electrical Containment Penetrations and Connectors," it is concluded that "...their design is adequate assuming that the results of the LOCA environment tests are positive." Regarding Cable Trays, it is concluded that "...their design is adequate... ." However, for "A-C and D-C Switchgear" an assessment of environmental (as well as seismic) design adequacy could not be made since "No seismic or environmental qualification information...(was) made available for review and evaluation."

Analysis Change - No analysis change was made in WASH-1400 (final) in this area (Section 5.1, Appendix II).

Conclusion - The effects of aging on PWR electrical power system failures are probably adequately considered in view of the Appendix XI discussion on this and related matters, especially if the study is repeated in five years, and further consideration is given to this area as suggested in Appendix XI. It is judged that the LOCA environmental effects are not adequately considered in view of the Appendix X discussion, and especially due to the poor experience in this area as described in the Draft review(2).

c. *Probability too low for operator opening wrong breakers* - It was judged during the review of WASH-1400 Draft that the value of 10^{-4} assigned to the probability that the operator, under stress, would inadvertently open breaker 15H3 or 15H8 is too low.

Appendix XI Response - None specific to this area. However, the general topic of human reliability is discussed on pages XI 2-40 and XI 14-1.

Analysis Change - None. The value of 10^{-4} was used in WASH-1400 (final). (Ref: Fig. II 5-4, page II-261 and II-262, also Table II 5-3, page II-203.)

Conclusion - The value of 10^{-4} assigned to the probability of the operator inadvertently opening breaker 15H3 or 15H8 in WASH-1400 (final) appears too low.

d. *Evaluation of d.c. power unavailability inadequate* - It was determined from the review of WASH-1400 Draft that the probability of loss of the on-site d.c. power supply (assigned a value of 10^{-3}) was not sufficiently justified, particularly in view of the fact that loss of d.c. power would interrupt power to the safety systems requiring power to operate independent of the availability of a.c. power.

Appendix XI Response - None.

Analysis Change - None (pages II-81 through II-95).

Conclusion - The assessed probability for d.c. power unavailability (10^{-3}) used in WASH-1400 (final) is not sufficiently justified.

Miscellaneous Comments - It is stated on page II-92, WASH-1400 (final) that "For the d.c. buses, unavailability (of power) at LOCA is represented by the coincident loss of offsite power and the station battery." This statement is not entirely true based on a review of the emergency power system which indicates that loss of the d.c. power supply will interrupt power to the safety systems even if offsite power is available. Fault trees contained in WASH-1400 (final) (Sheets 1 through 3 of Figure II 5-4, pages II 255 et seq.) correctly show this relationship.

e. *Insufficient consideration given to operator error (opening wrong breakers)* - It was concluded from the review of WASH-1400 Draft that several breakers not considered could be inadvertently opened by the operator failing critical portions of the PWR electric power system during LOCA.

Appendix XI Response - None.

Analysis Change - None (pages II-81 through II-95).

Conclusion - The apparent deficiency still exists in WASH-1400 (final).

f. *Maintenance errors resulting in power bus unavailability not considered* - It was determined during review of WASH-1400 Draft that maintenance errors, such as improperly racking breakers in or miscalibration of relays did not appear to have been considered in assessing the PWR electric power system failure.

Appendix XI Response - A general response applicable to this comment, although not specifically addressed to it, appears on page XI 2-4 and page XI 14-2. These responses generally indicate that maintenance induced errors have already been included in the data base because it is derived for the most part from field experience.

Analysis Change - None (pages II-81 through II-95).

Conclusion - It is concluded that maintenance errors of the type described have probably been accounted for in the manner described in Appendix XI.

g. *Possible incomplete consideration of diesel generator unavailability* - From the WASH-1400 Draft review, it could not be determined whether all of the concerns expressed in Appendix II, Vol. 2 (pages 35-38) regarding the inadequacies relative to diesel generator operation and reliability were appropriately considered in the fault tree analysis of the system. In view of the importance of the diesel generators as a source of emergency power during LOCA, it was concluded that WASH-1400 should have included a more complete description of how these inadequacies were considered.

Appendix XI Response - None.

Analysis Change - None (pages II-90 through II-92).

Conclusion - This apparent deficiency still exists in WASH-1400 (final).

h. *Common mode failures due to earthquakes, relay failure, and breaker location not considered* - The following three apparent common mode deficiencies were identified as a result of the review of WASH-1400 Draft: (1) In view of the fact that, according to Appendix X, neither the a.c. nor d.c. switchgear could be assessed as to seismic design adequacy, common mode failure of the PWR electric power systems due to seismic events appears not to have been adequately considered, (2) A relay failure which could cause tripping of both the offsite and onsite power source appears not to have been considered, (3) A fireball, generated by a short circuit across a load breaker, could cause nearby circuit breakers to trip open. It does not appear that this potential has been evaluated.

Appendix XI Response - None specific to these areas. However, the general method by which seismic caused common mode failures were assessed is explained on page XI 15-2. Common mode failures in general are also discussed on pages XI 2-4, XI 3-1 (et seq.) and in Addendum I to the main report.

Analysis Change - None.

Conclusion - The consideration of electric power failure due to seismic events appears to have been adequately considered in WASH-1400 (final) based on the discussion contained on page XI 15-2.

The other two potential common mode failures have apparently not been considered in WASH-1400 (final).

5. PWR High Pressure Injection System (HPIS)

Three discrepancies were found in this area during review of WASH-1400 Draft as follows:

a. *Operator reliability to open water valves to lube oil coolers too high* - It was concluded from the review of WASH-1400 Draft that (1) the probability of operator failure to open the service water valves to the standby HPIS pumps, if required, was too low ($1x10^{-3}$) and (2) the probability that the operator fails to open the service valve to the lube oil heat exchanger for the second standby pump given that he fails to open the first (10^{-3}) should be 1. Both of these apparent deficiencies were based in part on information contained in Appendix III, Section 6.1.

Appendix XI Response - None. However, the general area of human reliability is reviewed on page XI 14-1.

Analysis Change - None (Table II 5-21, page II-230)

Conclusion - The deficiency appears to remain in WASH-1400 (final).

b. *Low Pressure Injection System (LPIS) check valve failure not adequately considered* - It was postulated from the review of WASH-1400 Draft that a failure of any one of the check valves which are contained in each of the three lines connecting the HPIS to the LPIS would disable the HPIS during a small break LOCA. WASH-1400

Draft assumed that such a check valve failure would disable only one injection line, and the second line (to the remaining intact loop) would still be operable. In view of the fact that all LPIS fluid flows through a common header before branching out to the three lines (one to each primary system loop) it appears that failure of any LPIS check valve will divert most of the HPIS flow to the LPIS system.

Appendix XI Response - None.

Analysis Change - None (Section 5.6.4.4.3, page II-146).

Conclusion - This deficiency appears to exist in WASH-1400 (final).

c. *Additional double failures not included - Failure of both valves in (1) volume control tank drain, (2) normal charging line, (3) boric acid recirculation system* - It was determined from the review of WASH-1400 Draft that the three double failure combinations listed were not included in Section 5.10 which analyzes the HPIS.

Appendix XI Response - None.

Analysis Change - None (item b, page II-146).

Conclusion - The deficiency remains in WASH-1400 (final).

6. PWR Small Break Loss of Coolant Accident Analysis

The following assessment resulted from review of WASH-1400 Draft:

a. *Assumption of adequate core cooling for small breaks not justified* - It was concluded from the review of WASH-1400 Draft that the (implied) assumption of adequate core cooling for all small breaks assuming that emergency core cooling (ECC) systems do not fail was not justified. This conclusion was based on a rather extensive survey and comparison of analytical results from small break analyses performed by the PWR vendors.

Appendix XI Response - On page XI 2-5, in response to the above assessment, it is stated that "...the peak temperatures predicted by different PWR reactor manufacturers vary between 1100 and 1400F ...," and that "...(this) temperature range...is well below the NRC peak clad temperature limit of 2200F. Thus, from the viewpoint of reactor accident risk assessment, the study believes that the expressed concern in this area is not germane."

Analysis Change - None (page I-44 et seq.).

Conclusion - The Appendix XI response is incorrect in stating a temperature range between 1100 and 1400F. The actual range found during the review and quoted in Reference 2 was from 1075 to 1740°F. A recent calculation(7) shows a maximum temperature of 1657°F for a break size of 0.5 ft^2, a size which was not selected to produce the maximum temperature. In addition, it was concluded during the WASH-1400 Draft review that "The fact that in none of the calculations do core temperatures become great enough to cause damage that may lead to melting provides some confidence that adequate core cooling may be achieved. However, the large differences in results indicate that the processes occurring during the accident are not well understood, and that significant effects may be overlooked or improperly considered. In view of the fact that the small break

LOCA is a dominating contributor to public risk from PWRs, it is imperative that a substantial justification be provided to establish that ECC systems are adequate for small break LOCAs."

It is concluded that the assessment of this area as applied to WASH-1400 Draft applies to WASH-1400 (final). For a related discussion concerning ECCS functionability, see Section VI, "Additional Comments."

7. PWR Loss of Power Transient Accident Sequence

The following area was found to be inadequately assessed during the review of WASH-1400 Draft:

a. *Containment failure sequence* - It was concluded during the review of WASH-1400 Draft that the possibility of containment rupture when accumulator water impacts the molten core mass in the reactor vessel cavity following a loss-of-power transient was overlooked in WASH-1400 Draft. The rupture could result from either overpressurization from steam generation or damage from vessel head impact as a result of a steam explosion.

   Appendix XI Response - Page XI 12-1 states that "When water is introduced at the top of the melt...the potential for the coherent interaction of a large quantity of molten material with water is much smaller since the water cannot readily penetrate into or displace the high-temperature melt." On page XI 3-58, a discussion is given relating to the protection to the containment afforded by the overhead crane from missiles such as the reactor vessel head. It is concluded that "Since the crane is always present over the vessel centerline, the study concluded that the probability of such missiles (including the vessel head) leading to a breach of the containment is negligibly small."

It is stated on page VIII-13 that "Steam explosions in the reactor cavity are not expected to threaten containment integrity since the resulting pressures within the containment free volume are predicted to be small compared to the design levels..." However, it appears that this assessment applies to the double-ended pipe break LOCA and not to the loss of power accident discussed in the preceding discussion wherein two large containment pressure loadings may be superimposed. In the double-ended pipe break LOCA, the potential for reactor vessel steam explosion comes long after the end of blowdown and the containment pressure will have been substantially reduced. In the loss of power transient accident, it was postulated in the review of WASH-1400 Draft that the containment pressure loading from a steam explosion in the reactor vessel cavity comes immediately after the blowdown loading from vessel melt-through.

Analysis Change - None.

Conclusion - It is concluded that the WASH-1400 (final) response is inadequate regarding the likelihood of a steam explosion from the postulated molten core-accumulator water interaction. In the first place, the rate of water discharge onto the core melt will be quite high for the conditions postulated (several tons per second), and displacement and penetration of the melt by the water leading to coherent interaction (mixing) would appear likely. Second, the East German Slag Incident described on page VIII-78 of WASH-1400 (final), wherein two separate explosions were caused by spraying water on top of molten slag, seems to indicate that explosions under the conditions postulated cannot be dismissed.

Relative to the containment protection afforded by the overhead crane, there is in all PWRs a polar crane bridge located above the reactor vessel head. However, since the crane bridge is relatively narrow, and is located a considerable distance above the reactor vessel head, it is not clear how the bridge will be able to stop all conceivable reactor vessel head trajectories. In addition, there appear to be ambiguities on this matter within the Study. On page V-30 (Example 1, stated to be a PWR accident sequence on page V-30), it is stated "This (reactor vessel steam) explosion may have sufficient energy to fail the vessel and have the upper part of the vessel penetrate the containment structure." Also, on pages VIII-13 and VIII-17 (et seq.), there appears to be an implication that containment vessel damage by missiles from reactor vessel steam explosions is possible. At least there is no mention of the inhibiting influence of the polar crane bridge.

The overall conclusion to this problem is that the response in WASH-1400 (final) is considered to be partially adequate.

8. BWR-PWR Component Failure Modes and Rates

The following deficiency was identified during the review of WASH-1400 Draft:

a. *Assessed failure probability not consistent with data in several areas* - It was determined that the range and assessed median for some component failure rates used in WASH-1400 Draft were not consistent with the data. The components were pipes, pumps, and diesels.

Appendix XI Response - It is stated on page XI 14-2, in answer to another comment, that

> "As explained in Appendix III, the ranges assigned to the data are not deterministic bounds and therefore do not necessarily include all the source data. Thus, all source data need not fall within the assigned ranges. (It should be noted that in the calculations, the log-normal distributions themselves were used, and not the ranges.) Also, as explained in Appendix III, the ranges and distributions were not derived from simple empirical fits but involved some subjective judgments and decisions. Sensitivity studies were performed to investigate possible additional variations in the components mentioned, and few significant effects were obtained."

Analysis Change - Some of the problems cited were eliminated in Appendix III.

Conclusions - The explanation as given in Appendix XI and Appendix III for why the assessed component failure rates do not, in several cases, correspond to the rates from various data sources appears reasonable and may be valid. However, since few details were given relative to how the specific omponent failure rates were derived from the data, and the justification for adjustments which were made to the data, it is not possible to assess the validity of some of the failure rates used. Additional explanation regarding the derivation of some of the failure rates (particularly pipe ruptures, pump failures, relief valve failures, and diesel failures) appears to be needed.

9. Human Reliability Analysis

During review of WASH-1400, the following general deficiency was found in the treatment of human reliability:

a. *Inadequate and inconsistent derivation of specific human reliability assessments* - It was determined that some of the specific human reliability values used in parts of WASH-1400 Draft were not adequately or consistently derived and insufficient explanation was included to determine their validity.

   Appendix XI Response - On page XI 2-4, it is stated that "There is sufficient generalized information on human behavior to permit a valid quantification of human error probabilities for use within the accuracies needed for risk assessment." On page XI 14-1, it is concluded that "The study also believes, however, that more effort in the future devoted to a better understanding and modeling of human reliability factors would be useful.

   Analysis Change - None (Appendix III and related areas).

   Conclusion - Deficiency still exists since no additional information was provided in support of the specific human error probabilities used in WASH-1400 (final).

10. Common Mode Failures

During review of WASH-1400 Draft, the following deficiency was noted:

a. *Insufficient description of how common mode failures were quantified and applied* - It was concluded from the review of WASH-1400 Draft that it was not possible to determine if common mode failures were properly considered and accounted for. This was due in part to a lack of a clearly defined, systematic approach to identifying and evaluating common mode failures.

Appendix XI Response - In responding to other criticisms of WASH-1400 Draft similar to that described above, Appendix XI includes substantial discussion of how common mode failures were handled and their general significance. These discussions are included on page XI 3-22 (Section 3.1.2) and in various parts of Section XI 3-1.

Analysis Change - None apparent (Appendix IV and related areas).

Conclusion - While some clarity has been provided in WASH-1400 (final) relative to the general treatment of common mode failures, the deficiencies described above were not significantly improved. Thus, by and large, the deficiencies still exist in WASH-1400 (final).

11. Design Adequacy

During review of WASH-1400 Draft, the following deficiency was noted:

a. *Insufficient description of the extent to which design adequacies were assessed and applied* - It was determined from the review of WASH-1400 Draft that the completeness of the design adequacy study could not be assessed. In addition, the application of the results of the design adequacy study was very obscure.

Appendix XI Response - A general response relative to this issue is presented on page XI 2-4, which indicated that appropriate adjustments were made due to the inadequacies found in Appendix X.

Analysis Change - None (Appendix V; some minor changes made in Table V 2-2).

Conclusion - Insufficient information exists in WASH-1400 (final) to conclusively determine the extent to which design adequacies were assessed and applied. Thus, the deficiency remains.

12. PWR Low Pressure Injection System (LPIS) Failure

The following deficiency was found during review of WASH-1400 Draft:

a. *Incorrect value assigned to probability of operator closing second (wrong) valve* - It was determined from the WASH-1400 Draft review that the value ($1x10^{-3}$) assigned to the probability of the operator closing the second incorrect valve (B01 or B03) should be 1.

Appendix XI Response - None.

Analysis Change - None (Appendix II, Figure II 5-32, page II-293, and Table II 5-16, pages II-218 and II-219).

Conclusion - The deficiency remains in WASH-1400 (final).

Miscellaneous Comment -- It is not clear why the probability of the operator incorrectly closing valve B01 ($1x10^{-3}$) is different than closing B03 ($3x10^{-4}$) as shown on Table II 5-16, page II-218 (a similar difference exists for values A01 and A03).

13. PWR Low Pressure Recirculation System (LPRS)

During review of WASH-1400 Draft, the following four deficiencies were found:

a. *Operator error: incorrect probability for failure to open valves* - It appeared, based on information contained in WASH-1400 Draft, that a value of 10^{-1} should have been used for the probability of operator failure to open either valve 1860A or 1860B rather than $3x10^{-3}$.

Appendix XI Response - None.

Analysis Change - None.

Conclusion - The deficiency still exists in WASH-1400 (final) (page II-182).

b. *Operator error: no consideration of single failure valve closure* - It appeared from the review of WASH-1400 Draft that "operator error, operator closes MOV 1890C" should have been included as a single failure under "Single Failures which can cause Insufficient LPRS Flow."

Appendix XI Response - None.

Analysis Change - None (Fig. II 5-6, page II-325).

Conclusion - This apparent deficiency exists in WASH-1400 (final).

c. *Valve faults incorrectly placed and counted twice* - The valve faults (B03 and B02 failures) were determined during review of WASH-1400 Draft to be incorrectly placed under the top event "Pump B01 Fails to Start and Pump A01 Fails to Continue Running." Further, it was determined that these faults should appear under LPRS suction and discharge line faults where they did not exist. Also, they incorrectly appeared again under "Pumps A01 and B01 Discontinue Running."

Appendix XI Response - None.

Analysis Change - None (Fig. II 5-64, page II-325).

Conclusion - The discrepancy exists in WASH-1400 (final).

d. *Failure due to operator switching to hot leg recirculation after hot leg break not considered* - It was assumed in WASH-1400 Draft (page 490 App. II, Vol. 2) that "...although no written procedures were found to be available, it was assumed that at some time during the first day following a cold leg break the LPRS should be realigned to inject into the hot legs..." It was determined that, if a hot leg break occurs, and the operator, assuming a cold leg break, switches to hot leg circulation, LPRS failure may ensue for the same reasons as stated on page 490, App. II, Vol. I of WASH-1400 Draft. Such an occurrence was not considered.

Appendix XI Response - None.

Analysis Change - None.

Conclusion - The omission of this consideration still exists in WASH-1400 (final).

14. Core Meltdown Analysis

The following conclusion was derived from the review of WASH-1400 Draft:

a. *Time to core melt excessive* - Based on an independent analysis of the time required for a PWR core to reach fuel melting temperatures following a LOCA, it was determined that the WASH-1400 assessment was some 11 minutes too long.

Appendix XI Response - On page XI 2-6, it is stated that the potential time differential determined above will not influence risks because (1) isotopes which are large contributors to the accident consequences have half-lives greater than one day (and thus radioactive decay for the 11-minute change in release will be negligible) and (2) the evacuation mode is insensitive to small variations in available time.

Analysis Change - None.

Conclusion - The WASH-1400 assessment of the significance of this time change appears to be correct. However, the time to melt in

WASH-1400 (final) is unchanged, and the difference still exists. It is also possible that the difference in core melt time could alter the accident sequence and the mode of containment failure.

15. Containment Failure Pressure

It was determined from reviewing WASH-1400 Draft that:

a. *The Surry containment failure pressure was not sufficiently justified and appears high* - An independent analysis of the Surry containment failure pressure determined that a failure pressure of 67.5 psig was as high as could be justified. The value used in WASH-1400 Draft is 85 psig.

Appendix XI Response - On page XI 2-7, WASH-1400 (final) states: "The containment failure pressure of 100 psia determined by the study represents a nominal failure pressure for the containment. A containment failure probability of 0.5 was assigned for the calculated pressure of 100 psia. The containment failure probability was represented as a continuous variable with a normal distribution about this value.

"It should be added here that the ITI report (contained in Reference 2) recommended a value of 67.5 psia (sic) for the minimum failure pressure. This is roughly equivalent to the 2σ lower bound of 70 psia used in the study. Appendix E to Appendix VIII has been rewritten to better clarify the approach taken and the rationale behind the nominal failure pressure selected." (The value of 67.5 psia is incorrectly quoted from the ITI report. It should be 67.5 psig.)

Appendix E (page VIII-133) has been rewritten in WASH-1400 (final) to clarify the approach.

Analysis Change - None (Appendix E to Appendix VIII).

Conclusions - The failure pressure selected in WASH-1400 (final) (100 psia) is considered to be, based on arguments presented in Reference 2, unjustified and too high.

The justification for the 2σ lower bound discussed in Appendix XI (and Appendix E to Appendix VIII) is not discussed. Usually, a standard deviation is obtained from data, and since no containment failure tests have been run, there are no data. The ultimate strength referred to in Appendix E of 140 psia is based in part on the ultimate strength of the steel. The concrete will undoubtedly fail at a pressure much lower than that required to strain the steel enough to develop its ultimate strength.

16. Containment Pressure Response

Based on an independent analysis of the PWR containment pressure response following a LOCA, the following conclusions were reached compared to similar analyses contained in WASH-1400 Draft.

a. *Containment failure time should be reduced for containment spray injection system (CSIS) and containment spray recirculation system (CSRS) failure* - It was calculated, based on methods and assumptions described in Reference 2, that the PWR containment failure time would be 63 minutes after the initiation of the LOCA with failure of the CSIS and CSRS safety functions. The failure time calculated in WASH-1400 Draft for this case was 230 minutes.

Appendix XI Response - None.

Analysis Change - None (Fig. VIII 2-6, page VIII-23).

Conclusion - The containment failure times have not been changed in WASH-1400 (final). The change could alter the calculated sequence and mode of containment failure.

b. *Containment failure time should be increased for loss of electrical power* - It was calculated, based on methods and assumptions described in Reference 2, that the PWR containment failure would occur about 100 minutes later (about 160 minutes after inception of LOCA) than that assessed in WASH-1400 Draft.

Appendix XI Response - None.

Analysis Change - None (Fig. VIII 2-7, page VIII-24).

Conclusions - The containment failure time has not been changed in WASH-1400 (final). The change could alter the calculated sequence and mode of containment failure.

The following areas consist of the second group of deficiencies described in the introduction of this section. These deficiencies are mainly related to general assumptions made in WASH-1400 and also to how the results are presented and evaluated. A detailed discussion of each area can be found in Part 3, Section VI of Reference 2. An assessment of the extent to which these deficiencies have been considered in WASH-1400 (final) is as follows:

17. Comparative Risk Curve

The following deficiencies were determined to exist as a result of the review of WASH-1400 Draft in the area of presenting risk comparisons between 100 nuclear power plants and man-caused accidents:

a. *Calculated vs actual risks not distinguished in comparative curves* - It was concluded from the review of WASH-1400 Draft that the comparative risk curves contained in the Summary Report and in the Main Report should indicate that the nuclear risks were calculated while the other man-made risks were based on actual data.

Appendix XI Response - None. (This is listed, along with others, as comment 4 on page XI 2-2, but is not discussed in the corresponding response.)

Analysis Change - None (Fig. 1-1, Main Report and Executive Summary).

Conclusion - While it becomes immediately obvious upon reading WASH-1400 that the nuclear risks are calculated and the other man-caused risks are based on data from experience, the curves which present these risks do not make the distinction. As long as the curves are kept in the context of the WASH-1400 (final) report, this lack of distinction in the curves is not important. However, these curves have been and will undoubtedly be reproduced in many other documents and publications in which the accompanying text often does not make the distinction. It is considered important that these curves clearly contain sufficient information such that the possibility of misinterpretation is minimized. It is thus concluded that the deficiency still exists in WASH-1400 (final).

b. *Calculational uncertainties not sufficiently emphasized* - It was concluded that the calculational uncertainties for nuclear plant risks quantified in WASH-1400 Draft should be clearly indicated on the risk comparison curves. Such curves in the Summary and in the Main Report did not contain any indication of calculational uncertainties for nuclear risks.

Appendix XI Response - It is indicated on page XI 2-3 that the curves in the final report have been modified to show risk uncertainties for nuclear risks.

Analysis Change - Footnotes have been added to the curves in the Executive Summary (which is reprinted in the Main Report) to indicate the assessed uncertainties in the nuclear risk curves.

Conclusions - The addition of the footnotes is considered an acceptable resolution to this problem. However, a better resolution would be to show the uncertainties on the risk curve itself as is suggested and illustrated in Reference 2.

c. *Latent deaths not sufficiently emphasized* - It was determined from the review of WASH-1400 Draft that the calculated number of latent fatalities were not sufficiently emphasized in presentations and discussions of nuclear risks. In particular, it was pointed out that: (1) the abscissa for the risk curves given in the Main Report (page 153) and in the Summary are labeled merely "fatalities." However, the fatalities depicted in these curves are only acute fatalities, and they were derived directly from curves in Appendix VI which are labeled "acute fatalities;" (2) the risk discussions in the Summary Report to WASH-1400 Draft exclude any mention of latent fatalities even though they are calculated to exceed the acute fatalities by large factors.

Appendix XI Response - On page XI 2-3, it is stated that the meaningful comparison of latent and acute fatalities "...is, in fact, a troublesome matter that was considered with some care by the study." The response goes on to state:

"The problem of placing radiation-induced latent cancer fatalities in perspective is especially difficult since it is well known that there are latent cancer fatalities attributable to many causes (air pollution, chemical agents, etc) in our society. Although there are sufficient data available to create models that can predict, albeit with some uncertainty, latent effects due to irradiation, there is not sufficient information to do so for other carcinogenic agents. Thus the study chose, as indicated in section 5.5.4 of the Main Report, to compare the various radiation-induced latent effects with the normal incidence of similar effects. For instance, in connection with latent cancer fatalities, it is shown that the numbers predicted due to potential nuclear reactor accident (sic) represent a small fraction of the normal incidence of cancers due to other causes. While in this type of comparison potential latent effects from nuclear accidents are contrasted with those occurring principally from non-nuclear, environmental causes, the comparison provides some degree of perspective and is considered fair because some epidemiologists have estimated that the majority of normally occurring cancer fatalities are due to environmental causes."

Analysis Change - Footnote 1 (page 1) of the Executive Summary has been added to indicate that the deaths indicated in the figures are for "those predicted to occur within a short period of time after the potential accident."

Conclusion - The response in Appendix XI is considered to be a valid assessment of the latent vs acute death situation. It is, indeed, a "troublesome matter" with no obvious easy resolution. However, it is still concluded that WASH-1400 is deficient in not sufficiently emphasizing latent deaths, for the following reasons:

1. The comparative risk curve abscissas are still labeled merely "fatalities," even though they include only acute (early) fatalities.

2. The discussion of the overall risks contained in the Executive Summary (repeated in the Main Report) includes very little discussion of latent fatalities.

3. A unique feature of reactor accidents compared to other accidents used in the risk comparisons is the very large latent deaths to acute death ratio. This ratio is calculated to be even larger in WASH-1400 (final) than it was in the Draft. For example, according to Table XI 4-1 (page XI 4-1), there are calculated to be, for the worst reactor accident, more than 10 latent fatalities for every acute. This is substantially greater than computed in WASH-1400 Draft.

Part of the difficulty may be in the apparent inconsistent and vaguely defined use of fatalities, illnesses and other latent effects. For example, Table XI 6-1 lists "early fatalities," "early illnesses," and "latent cancer fatalities" as categories. The comparisons on page 9 of the Executive Summary have categories of "Fatalities," "Injuries" and "Latent Fatalities." The Tables on page 10 use categories of "Fatalities," and "Latent Cancers." The Main Report (page 71 et seq.) uses "early fatalities (defined as occurring within one year after the accident)," "early illnesses," and "latent cancer fatalities;" Appendix VI uses these definitions also. It is not clear what the term "injuries" used by itself on page 9 of the Executive Summary means (early illness? cancers? genetic effects? etc).

Also, the use of "fatalities" (unmodified) appears to mean only "early fatalities," but it is not clear that this is always the case. Are "latent fatalities" and "latent cancer fatalities" synonymous? How many "latent cancers" result in "latent cancer fatalities?"

In conclusion, while WASH-1400 (final) does increase somewhat the emphasis on latent fatalities from nuclear power plants, it appears that more could and should be done. (See item 2, Section VI for a more extensive discussion of this matter.)

d. *Transition from solid to dashed lines in man-caused risks does not correspond to data* - It was determined from the review of WASH-1400 Draft that the dashed line portion of the man-caused risks do not correspond to the extrapolated portion of the curve. It was concluded that the curves should be revised to clearly indicate the point at which extrapolation commences.

Appendix XI Response - None.

Analysis Change - None (Chapter 6 of Main Report).

Conclusion - Deficiency exists in WASH-1400 (final).

18. Nuclear Plant Characteristics

The following areas relative to the characteristics of the 100 plants to be operating in 1980, and to which the WASH-1400 results are said to apply, were found to be deficient as a result of the review of WASH-1400 Draft:

a. *Distribution of plant type not considered* - WASH-1400 Draft used a simple averaging method to determine the risks from the PWR and BWR population (100 total plants) expected to exist in the year 1980. The method did not account for the fact that of the 1980 reactor plant population, PWRs will account for about 2/3 of the total. It was concluded that the calculation of risks from both plant types should be revised to reflect the preponderance of PWRs in the 1980 population.

Appendix XI Response - None.

Analysis Change - The risk curves have been revised to account for the larger number of PWRs in the 1980 plant population (Page 72 of Main Report).

Conclusion - The deficiency has been corrected in WASH-1400 (final).

Miscellaneous Comment - On page XI 17-1 of Appendix XI (final), it is stated that the 100 plants considered in the study consist "...of approximately equal numbers of PWRs and BWRs." In view of the preceding discussion, this statement is incorrect and is inconsistent with the Main Report.

b. *Risks computed based on incorrect power level* - WASH-1400 Draft assumed, in order to establish a radioactive source term for the risk calculations, that all of the 100 power reactors would be operating at 3200 MW. The actual average design power level of the plants was determined to be 2400 MW for the BWRs and 2650 for the PWRs, and it was thus concluded from the review of WASH-1400 Draft that the actual design power levels should have been used in the risk assessments.

Appendix XI Response - None.

Analysis Change - None (Appendix XI, page 11-1, response to Comment 11.4).

Conclusion - This deficiency exists in WASH-1400 (final).

c. *Application of Surry risk analysis to other PWRs not justified* - The Surry reactor is a 3-loop Westinghouse design PWR. It was determined during the review of WASH-1400 Draft that the 3-loop Surry plant design used to assess PWR risks is typical of only 14 of the 67 PWRs projected to be operating by 1980. There were found to be 5 separate PWR designs of which the Westinghouse 4-loop design was the most numerous (22 plants). It was concluded that the Surry risk analysis could not be assumed, a priori, to apply across the board to all PWR designs as was done in WASH-1400.

In order to obtain some indication of the extent to which the Surry risk analysis may apply to the more numerous Westinghouse 4-loop designs, a comparison between the two plants was made as part of the WASH-1400 Draft review. The differences between the two plants were investigated in six areas as appropriate to the risk assessments involved. Table VI shows the results of the comparison. The first column indicates the area investigated. The second column indicates whether or not the differences between the plants were extensive enough that the Surry analysis did not appear applicable to the Westinghouse 4-loop design as represented by the Trojan(8) reactor. The third column shows which systems were found to be similar enough such that the Surry analysis would apply, with minor or readily identifiable changes, to the Trojan plant. The last column gives a qualitative indication of whether the difference between the two plants would result in an increased or decreased risk from the 4-loop design. As indicated in Table VI, of the six systems analyzed, three were found to be similar enough between the two plants such that the Surry results were judged, with some modification, to be applicable to Trojan. Three areas were found in which the applicability was judged not to exist. For three of the areas, enough analysis was done to indicate qualitatively what the risk change would be in considering the 4-loop

TABLE VI - Application of Surry Risk Analysis to Trojan

Area Composed	Does Not Appear Applicable to Trojan	Appears Generally Applicable to Trojan	Potential Risk Change for Trojan
Electric Power System Failure	X		Decreased
High Pressure Injection System Failure	X		Increased
Low Pressure Injection System Failure		X	Decreased
Low Pressure Recirculation System Failure		X	Undetermined
Containment Failure Pressure	X		Undetermined
Containment Pressure Response		X	Insignificant

design. Two areas were judged to result in a decreased risk and one to result in an increased risk.

An analysis to indicate the applicability of the Surry risk assessment to plants manufactured by Combustion Engineering and Babcock and Wilcox (34 percent of the 1980 plants) was not attempted.

Appendix XI Response - On page XI 2-11, it is stated, in response to an Advisory Committee on Reactor Safeguards comment, that "While the study believes that the extrapolation of the results of the analysis of two reactors to the first 100 large light-water-cooled plants is generally valid and that the data base used in WASH-1400 for estimating accident sequence probabilities is adequate for the purpose intended, draft WASH-1400 made the following suggestions, as indicated in Section 7.4.2 of the Main Report:

1. It would be useful in the future to pursue the variations in design from plant to plant and from site to site that could potentially affect the applicability of the WASH-1400 results to 100 reactors.

2. It would be useful to collect more data on nuclear plant operating experience for use in future reliability and risk assessments."

A similar discussion is given on page XI 17-1 of WASH-1400 (final), where it is also stated that "...Chapter 7 of the Main Report discusses in some detail the validity of the extrapolation to 100 reactors and suggests that such extrapolation is likely to be conservative..."

Analysis Change - None.

Conclusion - The WASH-1400 contention that the use of the Surry risk analysis is probably conservative when applied to the 1980 population of 100 reactors appears to be valid. However, until the other reactor designs are analyzed in detail, the validity of the contention cannot be substantiated. It is considered likely that, for the purposes of the study and within the assessed error bounds, the application of the Surry risks to the 100 plants is acceptable. On the other hand, as the study recommends, it is considered necessary to investigate the other plants to determine which risk assessment areas are different than Surry and make appropriate analyses of these areas.

Miscellaneous Comment - The second recommendation in Appendix XI (No. 2 above) is not in Section 7.4.2 of WASH-1400 Draft, contrary to the statement in Appendix XI.

19. Realistic vs Conservative Assumptions

It was concluded from the review of WASH-1400 Draft that the following deficiency existed:

a. *Indicated realism not consistently used* - It was determined that, although WASH-1400 Draft contended (page 15, Main Report) that the objective was to perform a "realistic assessment," it did not seem to be consistently followed.

Appendix XI Response - None.

Conclusion - Conservative assumptions continue to exist in WASH-1400.

20. Comparison of Risks Between Nuclear and Other Means of Electrical Power Generation

The review of WASH-1400 Draft resulted in the following two assessments:

a. *Comparison between nuclear and non-nuclear electrical power generation risks is required* - A consideration of the comparison of risks between nuclear and non-nuclear electrical power generation is needed in order to judge the acceptability of nuclear power. Such a comparison was not provided in WASH-1400 Draft.

Appendix XI Response - None.

Analysis Change - None.

Conclusion - In order to evaluate the acceptability of nuclear power from the standpoint of risk, an analysis of risks from non-nuclear sources of electrical power generation is required.

b. *Inadequate emphasis that risks are only from in-plant accidents* - It was determined from the review of WASH-1400 Draft that inadequate emphasis was placed on the fact that the report only considered the risks from accidents in 100 nuclear plants, and did not consider risks from other parts of the fuel cycle, sabotage, Pu diversion, etc. In particular, risk curves are entitled "100 Nuclear Power Plants" which may give the erroneous impression that the curves depict all risks associated with the operation of the plants.

Appendix XI Response - On page XI 2-3 and XI 2-4, it is stated that "The study agrees...that the risks from nuclear power involve not only those from potential reactor accidents but also those due to normal reactor operations as well as considerations pertinent to the rest of the fuel cycle. These matters are outside the scope of this study, as indicated in section 18 of this appendix; however, the published literature contains a significant body of analysis of many of those areas." It is reiterated on page XI 17-1 that "Other types of nuclear facilities were outside the scope of this analysis."

Analysis Change - None. (See Curves in Main Report.)

Conclusion - It is concluded that WASH-1400 (final) does not adequately emphasize that the calculated risks from nuclear power are from accidents only in operating nuclear plants.

Miscellaneous Comment - The reference to Section 18 on page XI 2-4 is incorrect. It appears that the reference should be to Section 17, although the discussion does not correspond entirely to the description on page XI 2-4.

21. General Inconsistencies

It was determined from the review of WASH-1400 Draft that:

a. *Study contains inconsistencies in approach and level of detail considered* - It was concluded that these inconsistencies should be minimized.

Appendix XI Response - None.

Analysis Change - Some of the inconsistencies, based on comments received from various reviews, have been eliminated.

Conclusion - While WASH-1400 (final) has been improved over WASH-1400 Draft, some inconsistencies, as described in the preceding analysis, remain.

22. Conclusions

In concluding the General Observations section of Reference 2, the following points were made:

a. *Continuous upgrading of study required* - It was concluded that continuous, diligent effort must be applied to keep the study up to date by timely incorporation of reactor design changes, new designs, changing failure rates, etc. Only in this manner could undesirable trends be perceived and corrected. Also, the study should be extended to apply beyond 1980.

Response - It is stated on page XI 2-12 of Appendix XI that "The study further believes that a WASH-1400 type assessment of water reactors should be repeated in approximately 5 years. The intervening period should permit the collection of additional nuclear power plant failure rate data and the further development of the methodology to permit more precise assessments to be performed. It is important that the collection of data and the development of methodology be pursued vigorously if these goals are to be achieved." On page 138 of the Main Report, it is stated that "It would also be useful to repeat an overall WASH-1400 type risk assessment for water reactors in about 5-10 years."

Conclusion - The WASH-1400 responses to this comment are adequate, although there is some disparity over the recommended time period for a repeat of the study (5 years appears preferable). It is presumed that the efforts described in the Appendix XI response are, in fact, being pursued.

b. *Expansion to incorporate different reactor concepts required* - It was concluded that expansion of the study to incorporate different power reactor concepts was necessary.

Response - It is stated on page XI 2-1 that "The study agrees that it would be useful to pursue the areas outlined (different versions of contemporary light water reactors, high temperature gas cooled reactors, liquid metal fast breeder reactors, and variations such as barge mounted power plants) in future NRC work." Also, page XI 2-11 states "...efforts of the type reported in WASH-1400 should be continued in the future and that risk assessments of the same type should be performed in connection with advanced reactor designs such as the liquid metal fast breeder reactor and the high temperature gas reactor at an appropriate time."

Conclusion - The WASH-1400 response is adequate.

VI. ADDITIONAL COMMENTS

During the course of reviewing WASH-1400 (final), two areas were found which appear to be incompletely assessed which was not directly considered as part of the review of WASH-1400 Draft:

1. ECCS Functionability

The study received several comments relative to the question of success or failure of ECCS even if all components operate as designed. On page XI 7-1, a response to these comments is given, as follows:

> "The question of the success or failure of ECCS -- as a matter of functionability, as opposed to operability -- does not readily lend itself to analysis by the methods used in WASH-1400. Thus, the study decided to examine what level of failure probability would cause ECF to contribute to potential accident risks. As noted in Appendix V, section 4.2, sensitivity studies reveal that "...even if values as high as 10^{-1} for ECF failure (probability) were to be used, any contribution made would be within the accuracy of the overall calculations."
>
> "Thus, although there appears to be no current basis for making a rigorous quantitative assessment of the probability of ECF failure, the analysis referenced showed that even if ECF failure probability were as high as 10^{-1}, it would not change the results of the study significantly. It is the view of the study that the probability that ECCS will fail to cool the core adequately is less than 10^{-1}."

Two aspects of the above response need to be explored and clarified. These are:

a. The discussion in Appendix V pertains only to the problem of mechanical damage causing degradation and nonfunctionability of the ECCS. The question of whether, based on thermal-hydraulic considerations alone, the ECCS may not function as designed is not addressed. In view of the fact that ECCS systems have not been tested under conditions representing a LOCA, there would appear to exist some uncertainty in their ability to perform the intended function. Indeed, the NRC is sponsoring extensive programs (e.g., LOFT) to provide assurance that ECCS perform adequately. It would appear prudent for WASH-1400 to acknowledge the possibility of ECCS nonfunctionability in this regard, and expand the sensitivity investigations to determine the consequences of various degrees of nonfunctionability.

b. The Appendix V discussion considers only ECCS functionability loss from mechanical damage. It is thus implied that ECCS functionability need only be considered for large break LOCAS where the potential for mechanical damage is greater than for small break LOCAs. The Appendix V assessment subsequently includes only large break LOCAs in sensitivity determinations of nonfunctionability of ECCS. It is readily apparent that, since large break LOCAs do not contribute significantly to the risks from nuclear power, the risks are not sensitive to assumptions regarding ECCS functionability. In this regard, it is somewhat misleading to contend, as was done in Appendix XI and Appendix V, that "These sensitivity results for both the PWR and BWR...reveal that the overall results of the risk assessment would not be particularly sensitive to a wide range of ECF (emergency cooling functionability) failure probabilities..." It appears obvious that, since small break LOCAs contribute much more significantly to the risks, the assumption of ECF failure for these breaks would have a much larger effect on risks. In view of the wide variations in results from various PWR vendor calculations of small break LOCAs (see Reference 2, Part 3, Section V.A.6, and discussion in Section V, item 6 of this report), it would appear reasonable to assume that some uncertainty exists as to the thermal hydraulic interactions occurring during ECC injection during a small break LOCA. Such an uncertainty should be acknowledged and ECCS nonfunctionability for small break LOCAs should be investigated in WASH-1400.

2. Latent Cancer Fatalities

It was concluded during the review of WASH-1400 Draft(2) that the latent death risk from nuclear power accidents was not properly presented, and that the report tended to obscure this risk. Section V (item 17.c) of this report discusses the changes made in the presentation of latent death risks in WASH-1400 (final), and concludes that such presentations are still inadequate. The computation and presentation of latent cancer fatality risks from nuclear accidents is a very important and complex issue. In order to attempt to understand and evaluate the numerous considerations involved in these efforts, a further investigation of related areas in WASH-1400 (final) was undertaken. Several apparent problems were found to exist in these areas in WASH-1400 (final) as follows:

a. *Population considered* - WASH-1400 (final) assumes that for the worst accident considered, latent cancer fatalities would be distributed over a population of 10 million people (page 74, Main Report). It is not clear how such an exposure population was determined, but it appears to be excessive, especially in view of the fact that the entire population within a 25-mile radius of the 100 reactor sites was determined to be only 15 million (page 73). At any rate, using the normal cancer fatality incidence for 10 million people produces a large number of fatalities which is used as a comparison to determine the impact of the radiation-induced cancer fatalities from the accident.

b. *Averaging risk over the exposed population* - It is apparently assumed that the radiation-induced cancer fatalities occur at the same frequency over the entire population of 10 million persons. There is no consideration given in the comparisons in the Main Report to the fact that certain segments of this population, particularly those living near the site, may, due to higher doses received, experience a much greater incidence of cancer deaths. Thus, the risk due to cancer death may be much higher to some segments of this population than others. The use of the same fatality rate over the same (large) population of 10 million persons does not permit any consideration of variations in risk due to site (or radioactive plume) proximity. The latent cancer fatality distribution for discrete segments of the exposed population as a function of location needs to be explored in order to adequately assess the risks.

c. *Rate and risk from leukemia fatalities* - The fatalities due to leukemia, based on Table VI 9-5, account for over 23% of all cancer fatalities committed from the first year after the accident while the normal incidence of leukemia is about 4% (Table VI 9-9). Thus, the incidence of leukemia fatalities from a reactor accident would be accentuated. After the accident, then, the leukemia incidence would appear to be greatly increased over the normal rate since the rate for all cancers is higher after the accident, and the leukemia incidence rate represents a significantly higher proportion of radiation-induced cancers than normal. It is also important to note that, according to Table VI 9-1, reactor accident-induced leukemia affects particularly the young and unborn persons in the population, making at least the perceived risk greater.

Conclusions - It appears that the risk tables and curves presented in the Main Report both obscure and minimize the risk from latent cancer fatalities following an accident. It should be noted that the quantitative evaluations in this discussion are generally based on the worst accident postulated in WASH-1400 (final). However, the arguments apply to other accidents as well.

VII. REFERENCES

1. Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, WASH-1400 (NUREG-75/014), United States Nuclear Regulatory Commission (Oct. 1975).

2. Reactor Safety Study (WASH-1400): A Review of the Draft Report (Part 3, A Review of the Draft Report - Reactor Safety Study, by P. R. Davis, Intermountain Technologies, Inc.), EPA-520/3-75-012, Environmental Protection Agency (August 1975).

3. Reactor Safety Study - An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants (Draft), WASH-1400, United States Atomic Energy Commission (August 1974).

4. Meeting between P. R. Davis, Intermountain Technologies, Inc., and L. B. Claassen, P. K. Gururaj, and W. Sutherland, General Electric Co. (Jan. 23, 1976).

5. Technical Report on Anticipated Transients Without Scram for Water-Cooled Power Reactors, WASH-1270 (Sept. 1973).

6. Studies of BWR Designs for Mitigation of Anticipated Transients Without Scram, NEDO-20626, L. B. Claassen, E. C. Eckert (Oct. 1974).

7. Exxon Nuclear Company WREM-Based Generic PWR ECCS Evaluation Model - Volume III, Small Break Model, SN-75-41 (Aug. 20, 1975).

8. Final Safety Analysis Report - TROJAN Nuclear Plant, Portland General Electric Co., Docket No. 50-344, as amended through February 1976.

9. Transcriptions from Advisory Committee on Reactor Safeguards, Meeting of the Working Group on Anticipated Transients Without Scram (January 7, 1976).

VIII. GLOSSARY

BWR	Boiling Water Reactor
CSIS	Containment Spray Injection System
CSRS	Containment Spray Recirculation System
ECF	Emergency Cooling Functionability
ECC(S)	Emergency Core Cooling (System)
GE	General Electric Company
HPIS	High Pressure Injection System
LOCA	Loss of Coolant Accident
LPCI	Low Pressure Coolant Injection
LPIS	Low Pressure Injection System
LPRS	Low Pressure Recirculation System
NRC	Nuclear Regulatory Commission
PWR	Pressurized Water Reactor
RPS	Reactor Protection System